APRIL, 1960 • VOL. 16, NO. 4

SPE JOURNAL

The Official Publication of the Society of Plastics Engineers, Inc.

BEST OF ANTEC 1960

Starting on page 396, 7 best papers presented at the 16th Annual Technical Conference in Chicago, Jan. 1960

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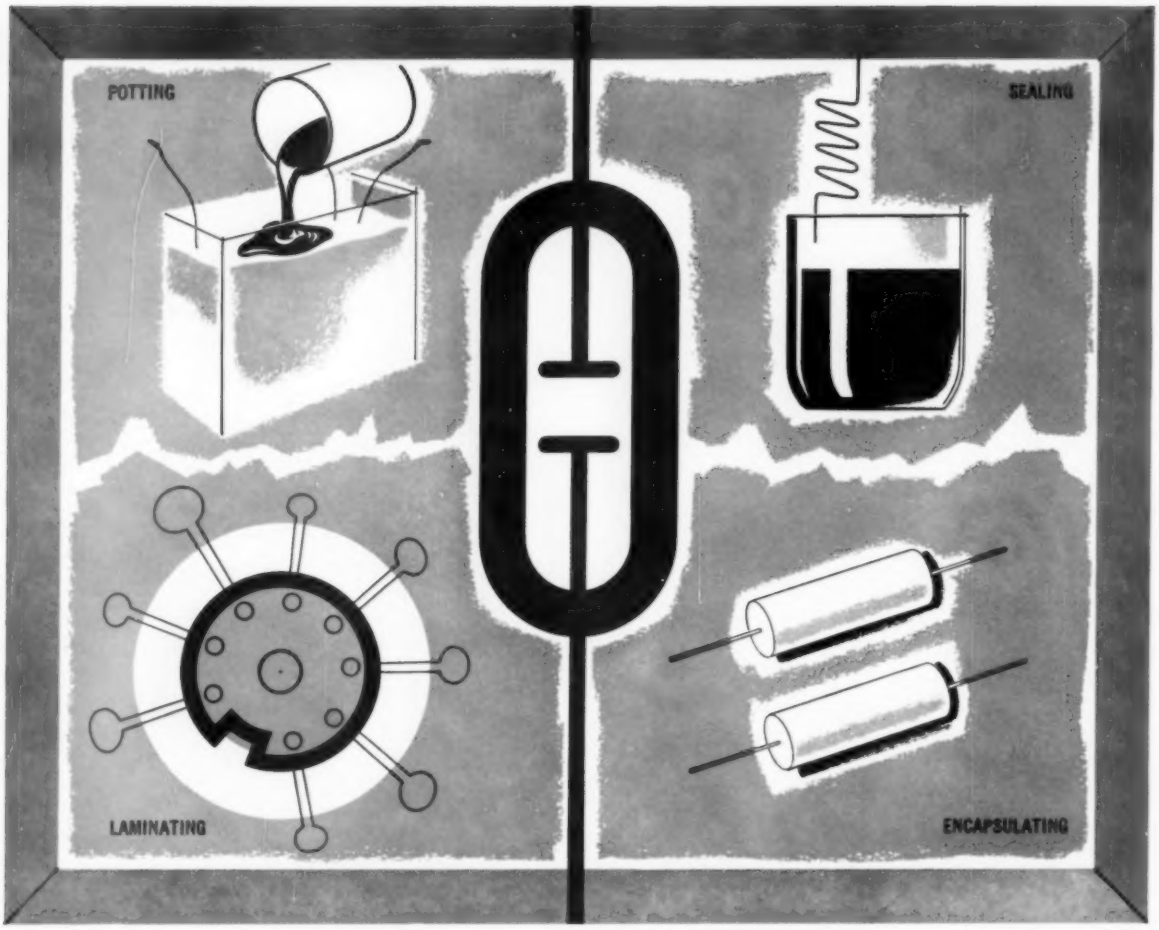

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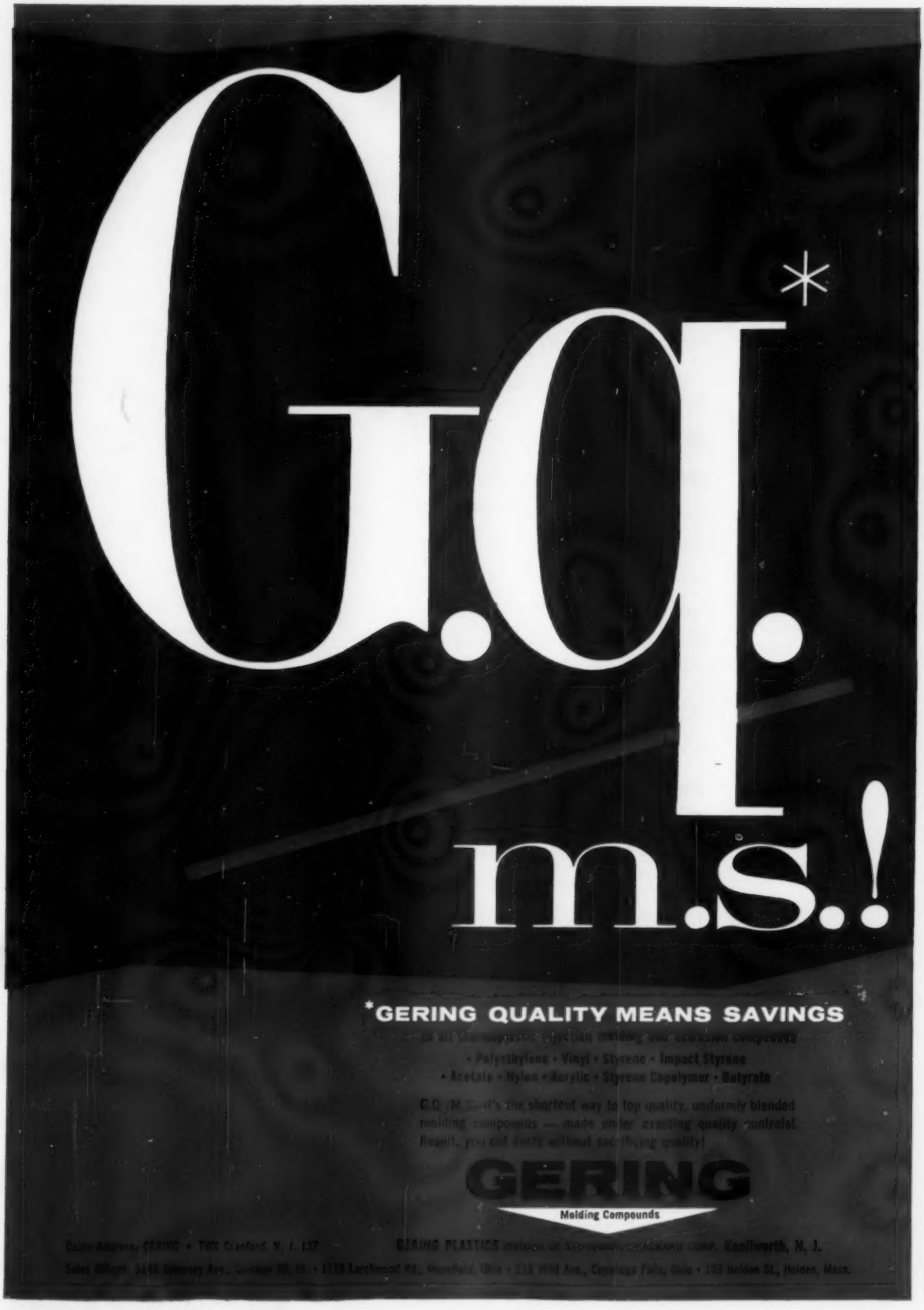
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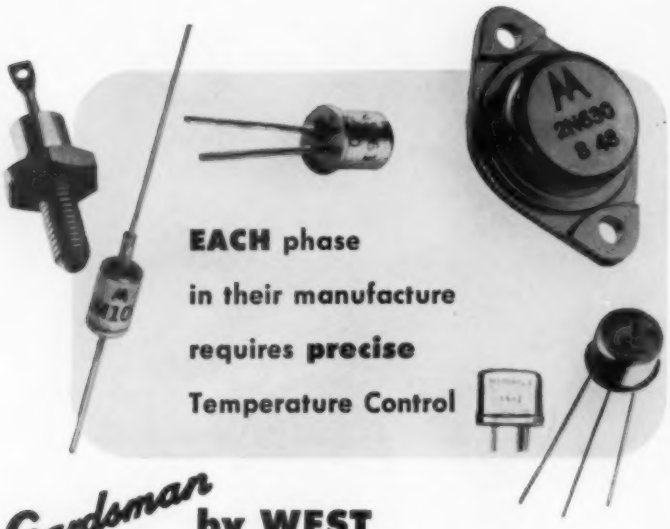

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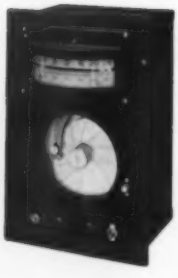

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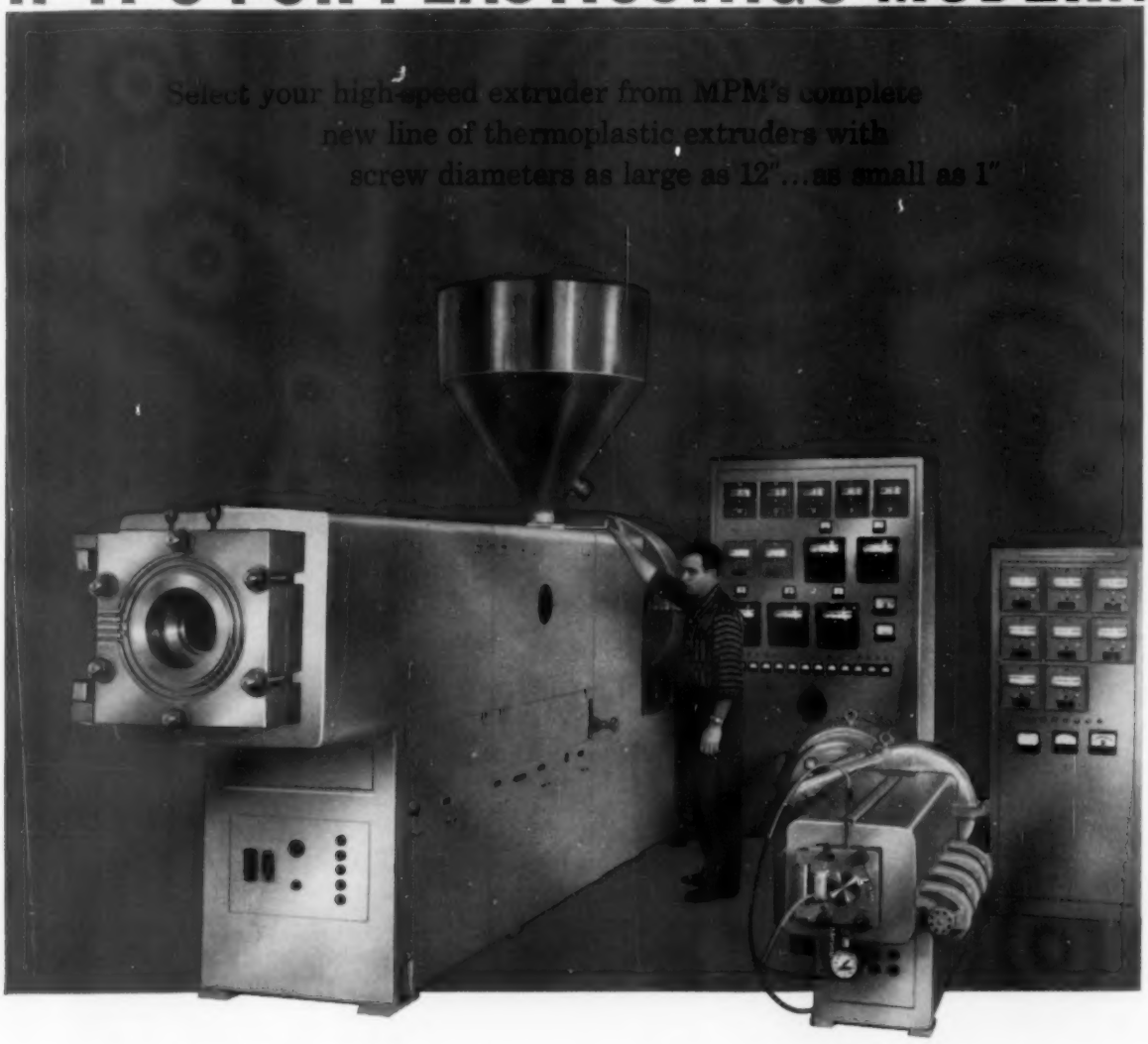
IF IT'S FOR PLASTICS...GO MODERN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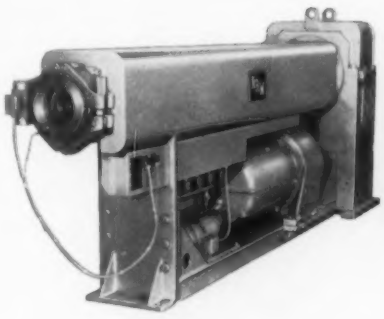

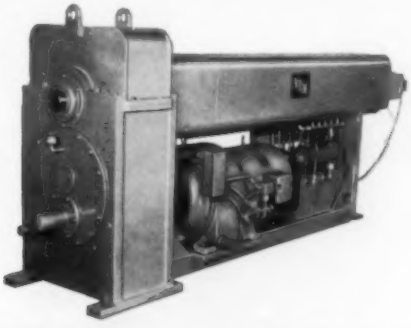

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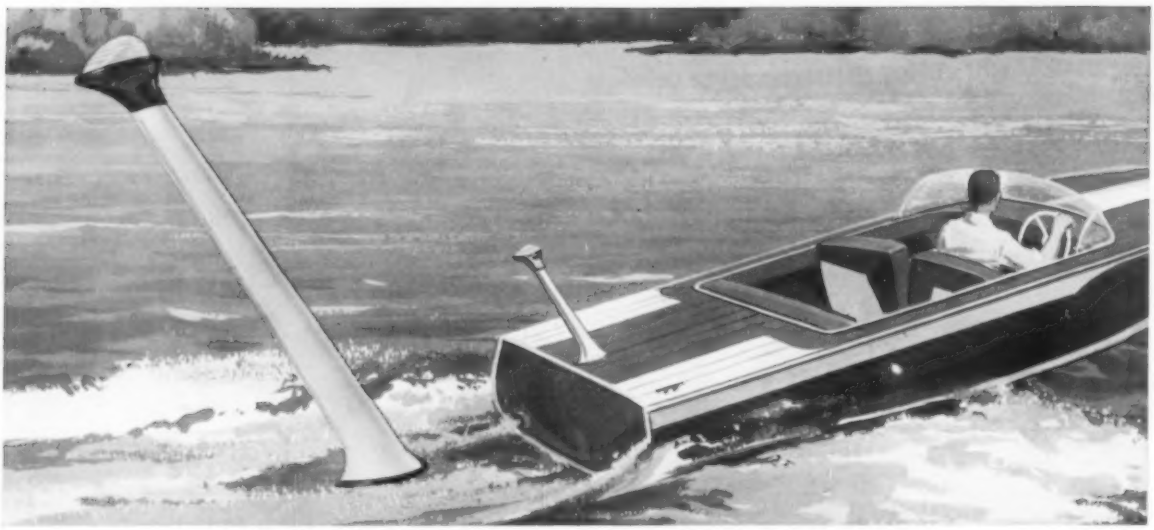

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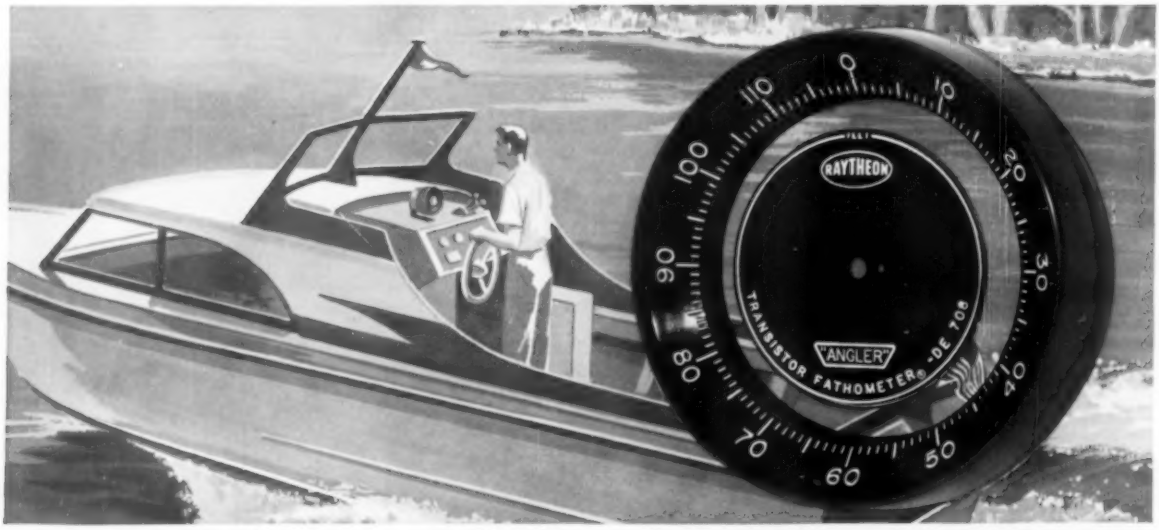

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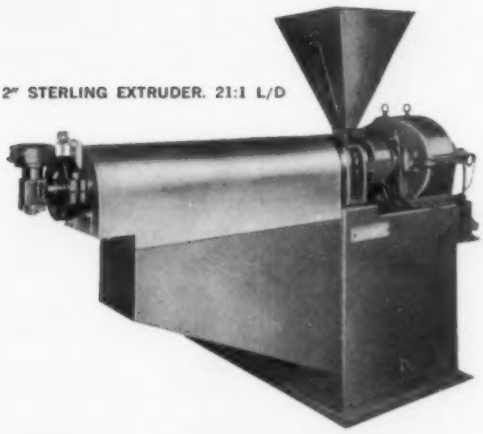

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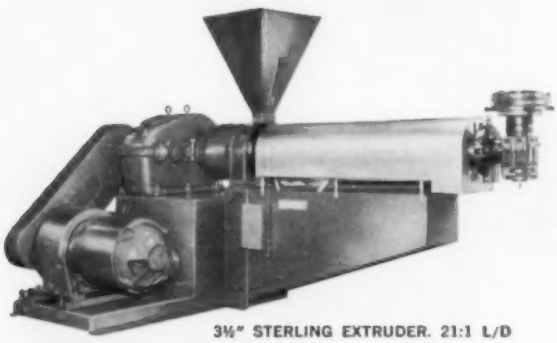

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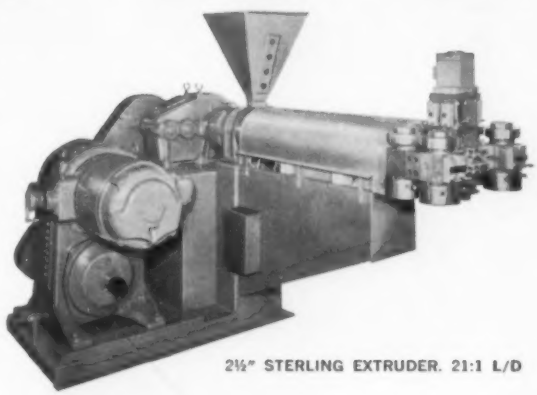

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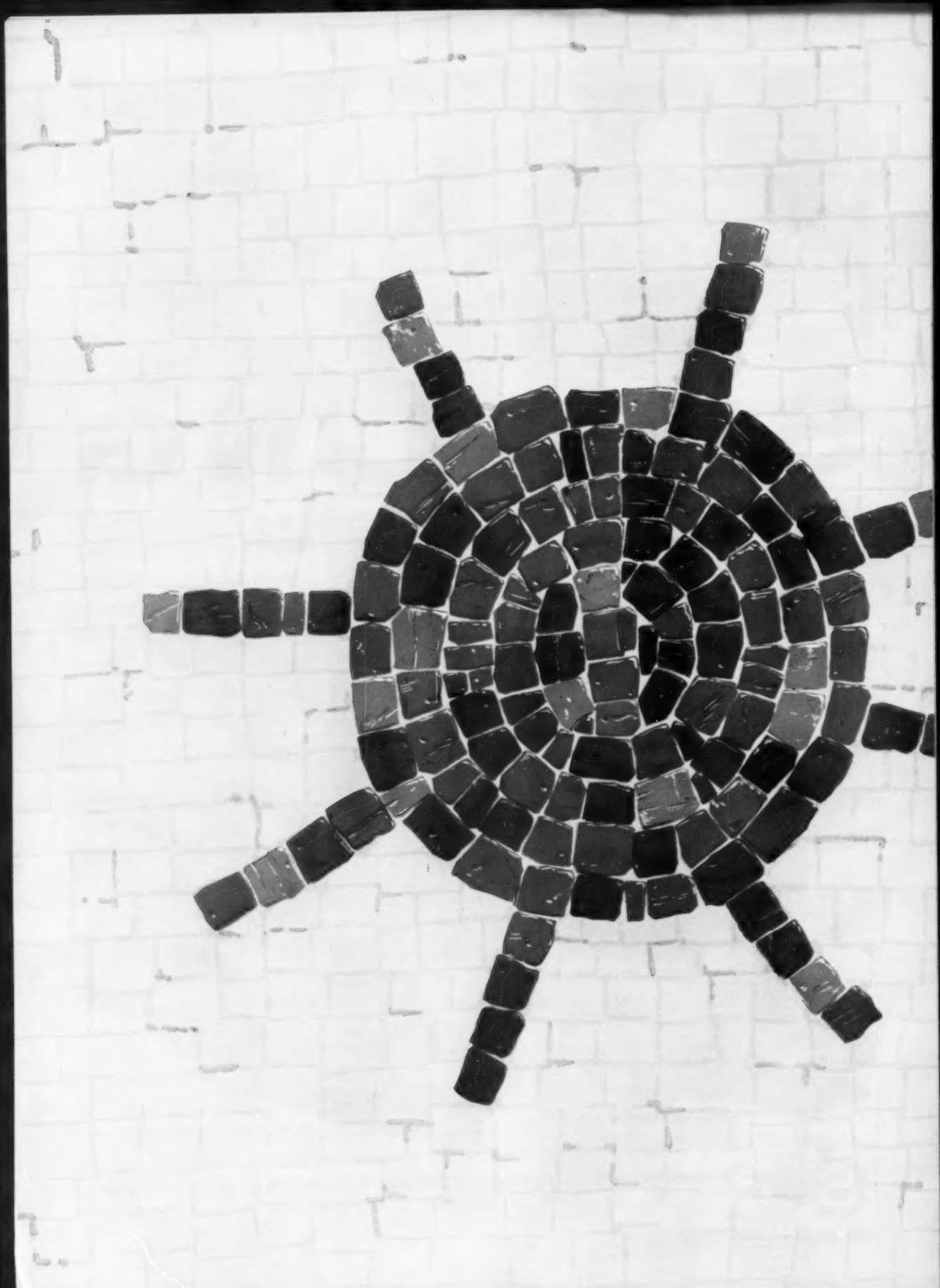

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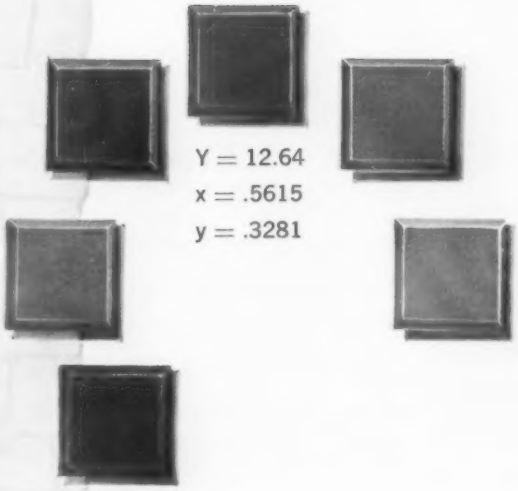

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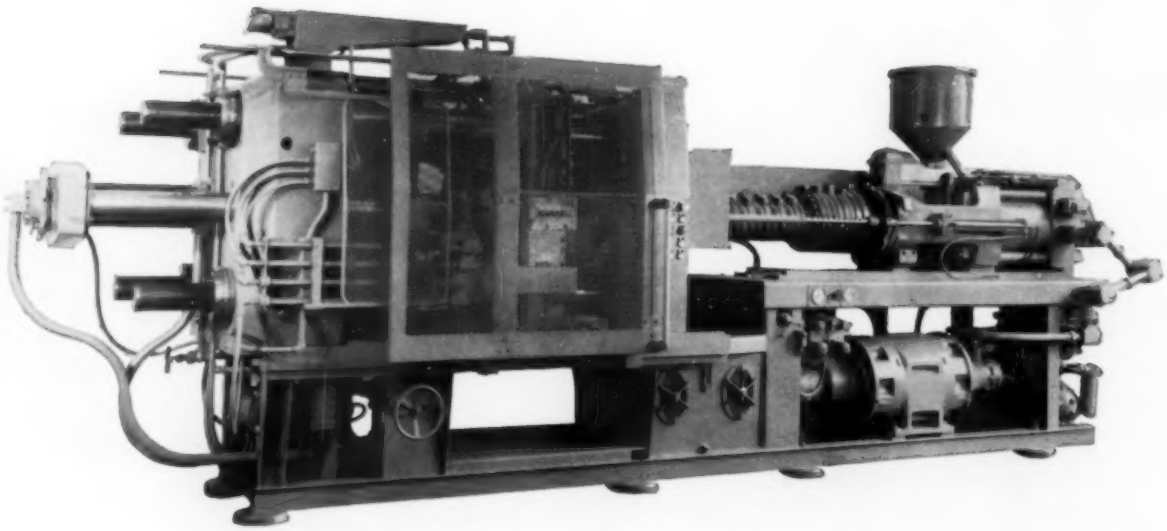

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DOW'S CLINICAL APPROACH TO HEALTHY PLASTICS APPLICATION

STUDIES OF GAS PERMEABILITY GIVE VALUABLE DATA ON MOLDING AND PACKAGING MATERIALS

Plastic barrier films often must have a specific resistance, or lack thereof, to gas and vapor passage, such as in the packaging of aerosols, carbonated beverages, and foods. Data on gas permeability, provided by Dow Plastiatrics studies, will be of value to plastics engineers and designers in the selection of proper barrier materials for use under known environmental conditions.

In the process of permeation—involving solution of the gas in the barrier material, diffusion through the barrier, and escape as a gas from the opposite side—permeability (rate of gas passage through a barrier of unit thickness) is a function of the diffusion rate and solubility of the gas in the barrier. Variables which affect permeability include temperature of the system, composition of the barrier, and size, shape and configuration of both the barrier molecules and gas molecules.

The general equation for gas transmission through a barrier is:

$$R = \frac{\overline{P} A \Delta p}{d}$$

where R = Maximum allowable gas transmission
$\overline{P}$ = Coefficient of gas transmission
A = Transmission area
Δp = Pressure differential across barrier
d = Thickness of barrier

This equation may be used to specify or evaluate the degree of resistance to gas passage obtained from a plastic material. However, $\overline{P}$ of the material must be measured experimentally. For example, $\overline{P}$ data for Saran Wrap* 7 and for Dow Polyethylene 610M are plotted on the basis of

$$\frac{\text{cc} - \text{mil}}{100 \text{ in.}^2 - 24 \text{ hrs.} - \text{atm.}}$$

in Figure 2.

Different sets of units are found in existing literature on permeability, and Figure 1 provides conversion factors for reducing the various units to common values.

Continuing Plastiatrics studies by Dow Plastics Technical Service Engineers are constantly developing new data on gas permeability of Dow packaging and molding material. For further information on these studies, write THE DOW CHEMICAL COMPANY, Midland, Michigan, Plastics Sales Department 1800EX4.

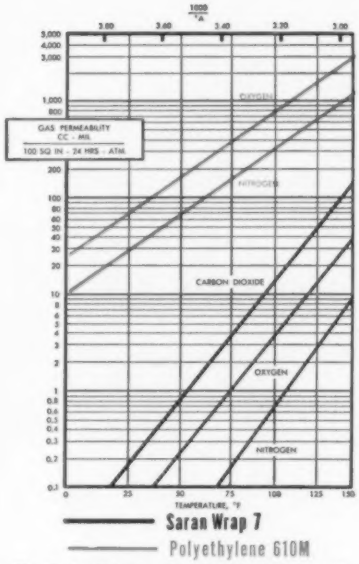

Fig. 2 Coefficients of Gas Transmission of Saran Wrap 7 and Polyethylene 610M, for various gases and temperatures.

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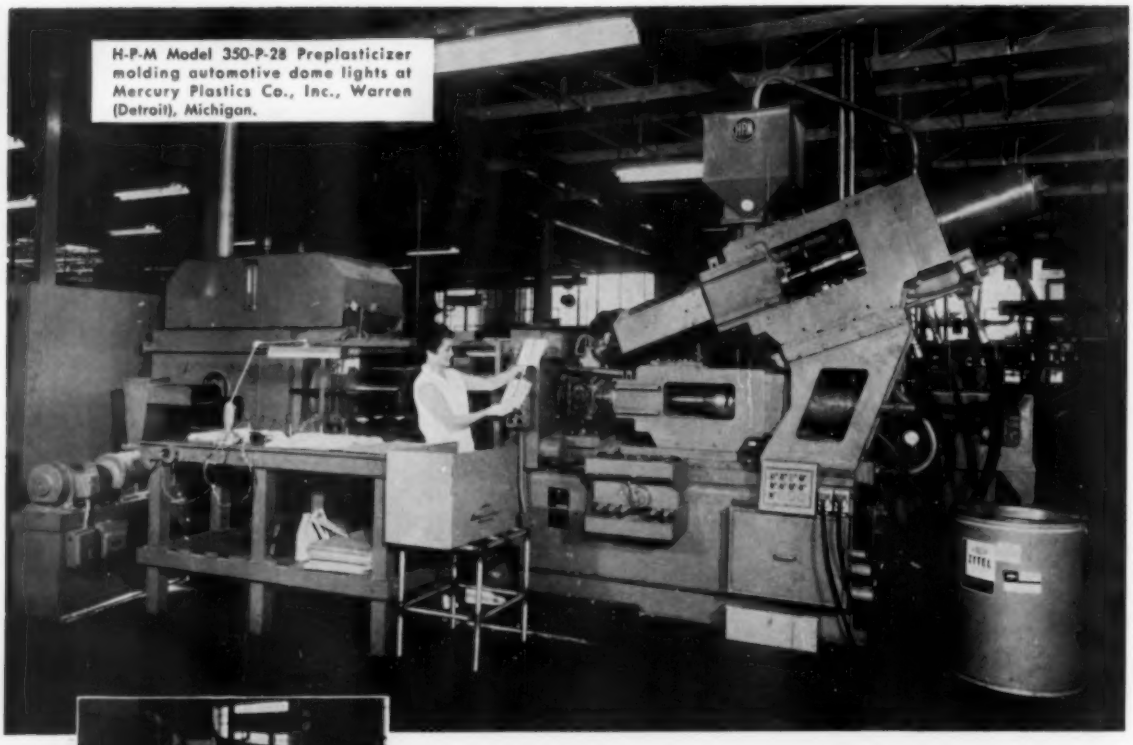
Polyethylene • PVC Resins • Pelaspan® • Saran
*Trademark

Fig. 1 Conversion factors for reducing permeability units to common values.

TO OBTAIN	MULTIPLY: cc-mm / m²-sec-cm Hg	cc-mm / m²-sec-atm	cc-mm / m²-24 hr-atm	cc-mil / 100 in²-24 hr-atm	cc-mil / m²-24 hr-atm	cu in-mil / 100 in²-24 hr-atm
cc-mm / m²-sec-cm Hg	1.0	1.32×10^{-3}	1.52×10^{-1}	6.00×10^{-6}	3.87×10^{-5}	0.98×10^{-6}
cc-mm / m²-sec-atm	76.0	1.0	1.16×10^{-1}	4.56×10^{-4}	2.94×10^{-3}	7.47×10^{-5}
cc-mm / m²-24 hr-atm	6.57×10^{0}	8.64×10^{0}	1.0	0.39	2.54×10^{-2}	6.45
cc-mil / 100 in²-24 hr-atm	1.67×10^{2}	2.19×10^{3}	2.54	1.0	6.45×10^{-2}	16.4
cc-mil / m²-24 hr-atm	2.58×10^{4}	3.40×10^{5}	39.4	15.5	1.0	2.54×10^{2}
cu in-mil / 100 in²-24 hr-atm	1.02×10^{6}	1.34×10^{4}	0.16	6.10×10^{-2}	3.94×10^{-3}	1.0

See "The Dow Hour of Great Mysteries" on NBC-TV

THE DOW CHEMICAL COMPANY • MIDLAND, MICHIGAN



H-P-M Model 350-P-28 Preplasticizer molding automotive dome lights at Mercury Plastics Co., Inc., Warren (Detroit), Michigan.

Shipments were increased 30% on this dome light when Mercury switched to an H-P-M P-28 preplasticizer.

Al Nick, Mercury Plastics, says,

"WE'VE INCREASED SHIPMENTS CONSIDERABLY ON NYLON PARTS

SINCE SWITCHING OUR AUTOMOTIVE DOME LIGHT MOLD FROM A CONVENTIONAL MACHINE TO OUR NEW H-P-M PREPLASTICIZER."

Other molders have enjoyed similar success with the new H-P-M 28 oz. machines molding such parts as nylon gears, valves, lacing strips and other parts. These new machines also have proven themselves for molding polyproplyene, acrylic and many other thermoplastic materials.

Two new 28 oz. H-P-M model preplasticizers are available. One has a clamping force of 200 tons, 25"/29" *daylight, 15" stroke and 15" x 26" mold space. The other has a clamping force of 350 tons, 34"/42" *daylight, 22" stroke and 20" x 34" mold space. Both machines are extremely fast and have plenty of plasticizing capacity for molding on minimum cycles. With accurate shot control, every part weighs the same.

It will pay you to talk with an H-P-M field engineer about these new Model P-28s before you buy. Write or phone, today.

**Daylight with ejector box removed.*

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HPM

H3

EDITORIAL

Education's Dividends

Almost every week, we receive letters in our office that start out somewhat as follows: "Plastics have always fascinated me, therefore I am using plastics as my chemistry project. I want to know how they are made and their many uses." This we quote from a letter received from a high school senior. But her curiosity seems to be the rule, and not the exception, these days. This is good, not only for the individuals and lay public concerned, but also for the industry. It is good for the uninitiated because plastics are now, and have been for some time, as much a part of our civilization as iron, tin, gold, copper, and aluminum. To have an appreciation of the technology of a material which contributes so much to the comfort and welfare of a civilization is, it seems, a desirable thing. Indeed, much of the advertising of companies producing plastics is written not with specific product appeal but with a distinct educational approach, for example, how oil and natural gas are used to create plastics. So then it becomes obvious that a-passing-acquaintance education in plastics is good not only for the lay public but for the plastics industry as well.

One step away from the general public is the army of doers and thinkers in industries other than the strictly plastics industry. Here, perhaps, is where education can reap the biggest dividends. Here is where transfer of knowledge can take place—from the plastics industry to the textile industry, to the metals industry, and to any number of other industries one can think of. This is where the technical societies and trade associations come in by sponsoring courses in plastics. To say that SPE's Sections have met this challenge would be an understatement. In fact, the Sections have actually held up the challenge for industry to see.

The third level where education can help the industry reap dividends is in our colleges and universities, both on the undergraduate and graduate levels. Notable successful examples are: Lowell Technological Institute, offering courses in plastics engineering and technology, the Plastics Program at Princeton University, offering science and engineering students a perspective of the activities and opportunities in the field of polymeric materials, and the now famous Polymer Research Institute founded by Dr. Herman Mark at the Polytechnic Institute of Brooklyn. The challenge is out. But, thanks to farsighted and dedicated plastics engineers and scientists, the machinery is available to meet it.

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This valuable guide to the use of natural pearl essence and synthetic pearl pigments is yours for the asking.
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Prominent toy manufacturer operates their fully automatic Van Dorn 3 oz. presses 24 hours per day, 6 days per week. They also report their Van Dorn presses substantially reduce cycle time, are economical, versatile, and require minimum maintenance.

Model H-300

GAIN 3 WAYS with VAN DORN Presses

Model H-400

Model H-260

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The user of this Van Dorn 4-6 oz. press had a well conceived idea for a plastic part, but no molding experience. So they had Van Dorn engineers help them procure a well designed mold from a competent moldmaker; then checked the operation of the finished mold on a Van Dorn factory demonstration unit. This free Van Dorn "Package Service" insures satisfaction, helps produce profits.

"25% LESS CYCLE TIME"

This is the report of a progressive custom molder about his Van Dorn 2½ oz. presses. He also says that they "give fast set-ups, and less waste in purging from one material to another. Van Dorns are extremely fast, versatile and economical."

Write for Illustrated Specification Bulletins on these Van Dorn Plastic Presses.

Van Dorn

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SPECIAL FEATURE

James O. Turner

Lawrence Radiation Laboratory

University of California

Plastics for Atom-Smashers

In the solution of design problems of atom smashers, many plastic materials have played indispensable parts. They provide combinations of mechanical and electrical strength, flexibility, toughness, chemical and temperature resistance, and optical and vacuum properties—without which many nuclear-particle experiments would be impossible. These materials fall into virtually every classification of thermoplastic and thermosetting resins.

"Atom smashers", or high-energy nuclear accelerators, have produced some spectacular advances in man's understanding of the fundamental structure of matter. With their supporting apparatus, they form a class of highly complex instruments, whose designers are continually beset with tough and puzzling problems. They involve precise manipulation of pressure, vacuum, voltage, current, magnetic field, and temperature, sometimes to awesome extremes and often with microsecond timing.

We at the Lawrence Radiation Laboratory have come to depend heavily upon a class of materials known as plastic scintillators. The principal ingredient of this material is styrene. Certain complex organic phosphors or fluors are dissolved in the styrene monomer, and then the solution is carefully polymerized by the application of heat. When the material has solidified, it is then cut and polished to final shape, and is usually combined with one or more pieces of highly polished acrylic plastic (*Figure 1*). The styrene scintillator emits visible light when traversed by beams of accelerated ionized particles. The scintillations, or flashes of visible light, are transmitted by the acrylic light pipe to one or more photomultiplier tubes. These convert the light pulses into electrical pulses, which then actuate electronic counters.

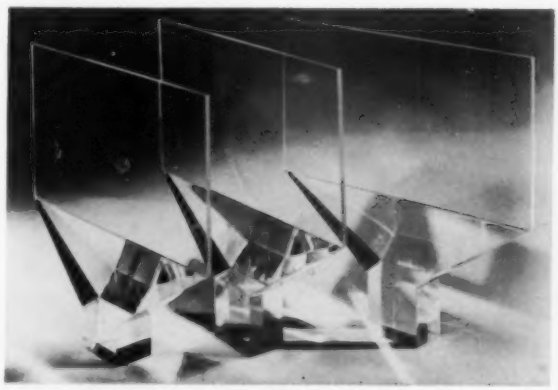


Figure 1. Styrene plastic scintillators attached to acrylic light pipes.

Also used extensively is a type of accelerated beam detector known as a Cherenkov counter. This can be made of any of a number of transparent materials, and is frequently made of highly polished acrylic plastic (*Figure 2*) This type of detector also gives off visible light pulses, which are picked up and counted in a manner similar to those from the plastic scintillators.

The high-clarity acrylic plastics have many optical applications in the shape of lenses, prisms, windows, etc. An unusual application is in a high-speed measuring projector for measuring images on film. It uses a rotating disc containing a series of slits, each at a different radius. Each slit as it rotates sweeps out an annular area. The light from each of these annular rings must be gathered and focused into a stationary photomultiplier tube. This is accomplished with an acrylic lens containing a series of concentric elements, each matching one of the annular zones but having its focus offset in a direction different from the others.

The excellent electrical properties of acrylic plastics are utilized in a wide variety of ways. One application is as a container for oil-submerged high-voltage reactor cores which are part of the accelerating-electrode power supply for the Bevatron. Another of these applications is as a stabilizing resistor, which was constructed of an acrylic tube filled with distilled water.

In some cases involving the construction of high-voltage apparatus, because of the hazard of fire, it is necessary to adopt materials of good electrical properties which are also self-extinguishing. Such a material is transparent vinyl chloride acetate. This material is currently used more and more where both good electrical properties and transparency are required, such as in the side windows in recently constructed focusing quadruple magnets. Another material quite useful in the construction of high-voltage apparatus, which also must be self-extinguishing, is poly (vinyl chloride) or "PVC". A recently completed Cockcroft-Walton 500,000-volt generator uses PVC to enclose the end compartments of the various decks and vinyl chloride acetate to enclose the center sections of these decks (*Figure 3*). Polyvinyl chloride is used for many high-voltage constructions that must be self-extinguishing and are not required to be transparent. Another instance is a 20,000-volt reversing switch.

This article adapted from a paper presented at the 16th ANTEC—Chicago—January, 1960

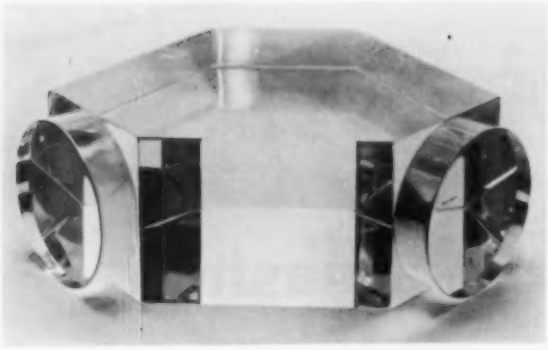


Figure 2. Acrylic Cherenkov counter.

Figure 3. Cockcroft-Walton high-voltage generator of polyvinyl chloride and vinyl chloride acetate.

One recent problem involved a severe optical requirement. This was the construction of a highly specialized retrodirective reflector that would reflect light very accurately, would not produce any reflected images, and would withstand submersion in liquid hydrogen at a temperature of approximately minus 450°F. A system of reflecting lenses with curved cylindrical surfaces was finally worked out, and the material which was found to be best suited to these conditions was clear allyl plastic plate from which the lenses were machined and polished.

Polyethylene provides the solution for a number of problems. One example is for "Spitzers", or transfer pipettes for the handling of highly corrosive radioactive chemicals. Another recent application is the outer enclosure of a special large ionization chamber (Geiger counter). The lower part of the outer shell was constructed of black high-density polyethylene, and welded to it was a flat end plate of white high-density polyethylene *(Figure 4)*.

An almost indispensable material to us is high-strength polyester film. It is used for insulation of many coils involving large size square and rectangular conductors and also as containers for liquid hydrogen when used as beam targets inside of vacuum tanks.

Polycarbonates Used

A new material which promises to be of considerable use because of its exceptionally high impact strength and dimensional fidelity is polycarbonate which we have already used in a number of applications. A high-precision adjusting thumb screw is a typical example.

Fluorethylene has many useful properties. An unusual one is the fact that an electric arc improves rather than degrades the electrical properties of the surface of the material. This has been used in the construction of a high-current (2,000,000-amp) pulsing switch for thermonuclear research. The fluorethylene forms

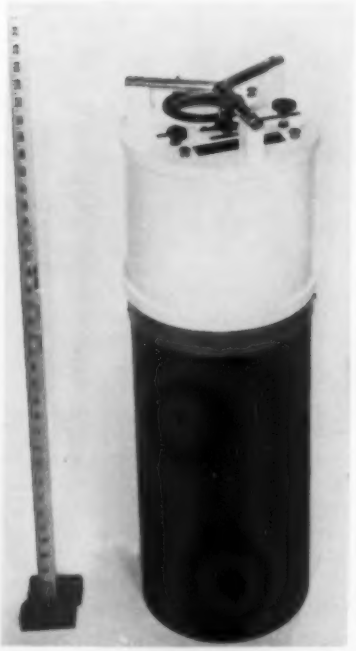
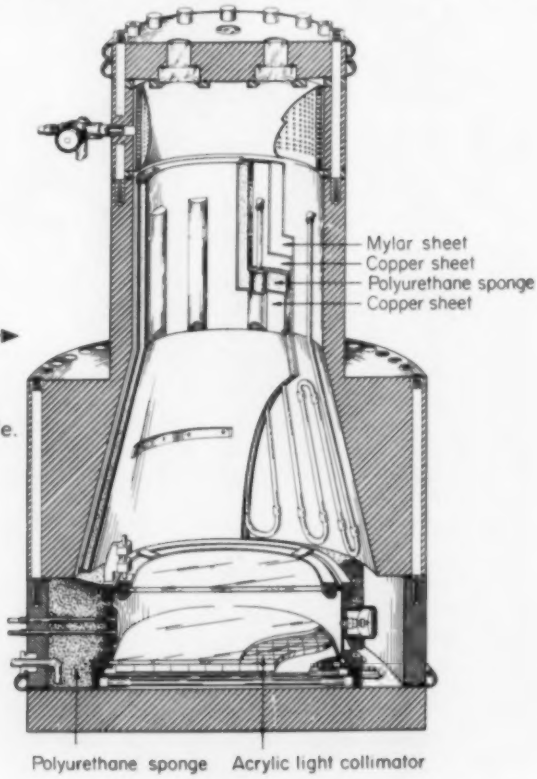


Figure 4. Ionization chamber (Geiger counter) of high-density polyethylene.

Figure 5. Propane bubble chamber showing polyurethane sponge as an oil matrix-baffle.



the "tires" or grooves which support the large metallic arcing plates at their outer edges.

Soft, flexible, polyurethane sponge material has proved to be useful in a number of applications, including one in a propane bubble chamber. The polyurethane sponge is impervious to the oil in the chamber and acts as a stabilizing baffle *(Figure 5)*.

Laminates and Epoxies—Wide Range of Uses

One of the most useful materials to us is the NEMA grade G10 industrial laminate constructed of woven fiberglas and epoxy resin. This material has so much better mechanical, electrical, and vacuum properties than any other material that it has now been adopted as standard for nonmetallic constructions inside the Bevatron vacuum tank.

In providing insulation and mechanical support and separation for the separate turns and layers of coils wound from large-size copper conductor, laminates made from fiberglas mat, woven cloth, and polyester resin have proved to be economical.

By all odds, the single material that enjoys the widest variety of uses

Figure 6. Section of vacuum tank for electron synchrotron constructed of epoxy and fiberglas, assembled into ring tank.

is liquid epoxy resin. The number of different ways in which we use this material runs literally into the hundreds. A few random examples: In the assembly of the 72-inch liquid-hydrogen bubble chamber, it was necessary to make a joint between the bottom of the vacuum tank and the top of the magnetic yoke that would be both mechanically and magnetically as sound as possible. To avoid an expensive machining procedure, the joint was filled with a mastic formulated of epoxy resin and iron powder.

An electron synchrotron comprises a ring-shaped vacuum tank approximately 8 feet in diameter with an elliptical cross section. The original vacuum tank was constructed of quartz. Since it is sometimes necessary to replace sections of this vacuum tank, there has been a continuing effort to find a material more easily fabricated and less expensive than the original quartz. This was finally accomplished with the use of epoxy resin, fiberglas cloth and glass beads for fillers *(Figure 6)*. In this same machine it was necessary to modify a nonmetallic mechanical support ring to withstand very high magnetic forces. The alteration consisted of making a large elongated window or opening in this support ring. This was accomplished by the use of epoxy resin filled with glass beads and with horizontal steel rods used for reinforcement in the manner of concrete-reinforcing steel.

An insulating anchorage was required in the Bevatron for some quarter-inch steel bolts. These fastenings could not be of the usual type because of the corona resulting from an exceedingly high-voltage gradient. This was very neatly accomplished by providing spherical heads for the bolts and imbedding them in holes in the insulating support, the holes being filled with epoxy resin.

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Here are some of the resin characteristics that FPE seeks and PLYOPHEN 5660 provides:

- Electrical properties that resist voltage breakdown in accordance with the rigid safety codes of the Underwriters' Laboratories.
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"RCI PLYOPHEN 5660 (phenol-formaldehyde resin) passes all these tests. Molded part rejections due to material failure are less than one-tenth of one percent," says Mr. Goody.

If *your* production calls for phenolics, remember that RCI offers over 40 individual types of PLYOPHEN, both liquids and powders, for bonding, laminating, impregnating or casting applications. Moreover, every RCI customer gets the benefit of expert technical assistance whenever required. Write today for complete information (state specific application).

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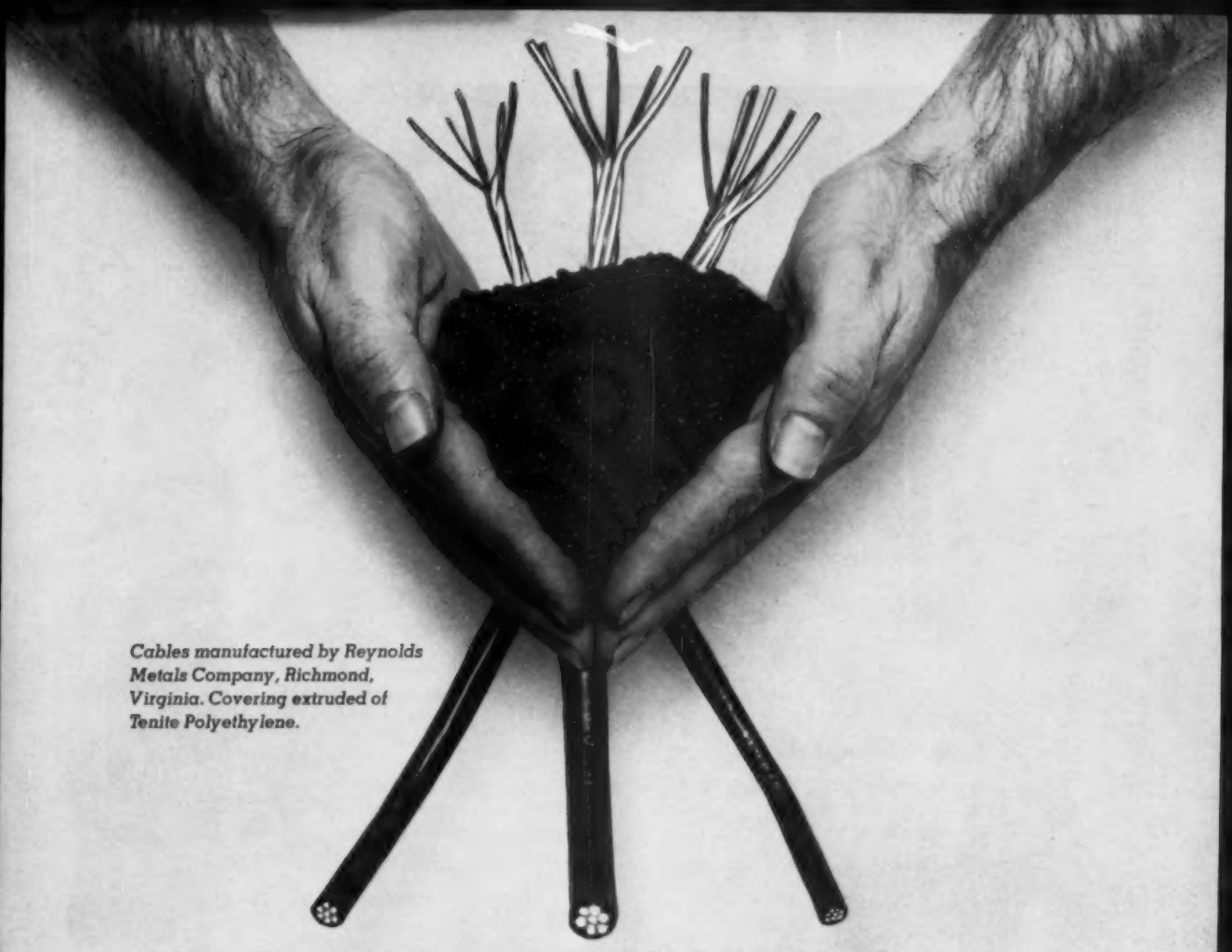

Cables manufactured by Reynolds Metals Company, Richmond, Virginia. Covering extruded of Tenite Polyethylene.

Why Reynolds covers these aluminum conductors with TENITE POLYETHYLENE

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Tenite Polyethylene is manufactured under as rigid a system of quality control as Reynolds' own aluminum conductors, and makes a tough, weatherproof, fast-stripping covering material which offers high dielectric strength and resistance to abrasion, heat, moisture, chemical attack and stress cracking. It remains flexible even at sub-zero temperatures and its light weight permits easy handling and wide spans. Users report that it gives long service life without festooning or splitting.

Tenite Polyethylene is easily extruded as jacketing or insulation for many diverse applications, from coaxials to control cables, from TV lead-ins to telephone wires. For a material with outstanding electrical, physical and chemical properties, specify Tenite Polyethylene. For further information, write EASTMAN CHEMICAL PRODUCTS, INC., subsidiary of Eastman Kodak Company, KINGSPORT, TENNESSEE.

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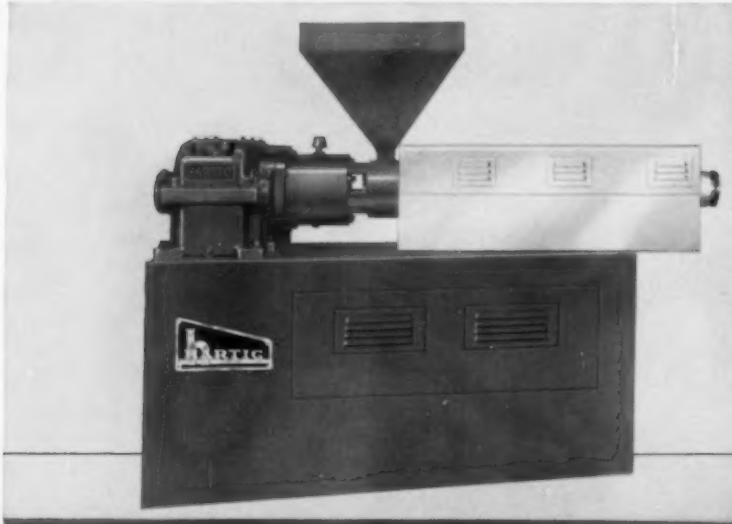

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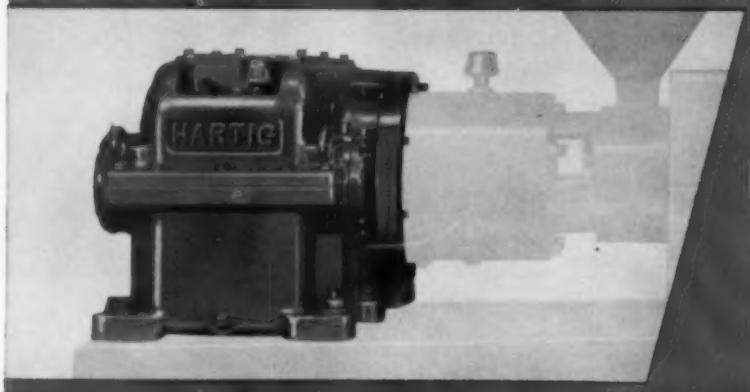

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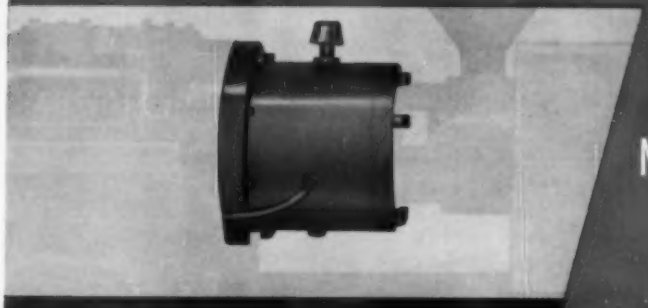

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SPEAKING OF EXTRUSION

Pressure Development in Extruder Screws

The simplest analyses of flow in extruder screws are generally based on assumption of isothermal conditions of the molten material in the delivery end of the machine. The pumping capacity of a metering section under this condition is reasonably well defined by the familiar relation: (1, 2)

Q = Open Discharge Rate − Back Flow

$$Q = \alpha N - \frac{\beta}{\eta} P \quad (1)$$

where Q = volume rate of discharge.
N = screw speed.
P = pressure drop across the metering section.
η = material viscosity.
α and β = constants involving channel dimensions.

Modern extruders are usually equipped with a pressure gauge at the end of the screw or in the head cavity and one is tempted to use the reading of this gauge in equation (1) to calculate a theoretical output rate. This assumes that the pressure at the entrance to the metering section is zero, a condition which, obviously, could not exist unless the screw flights were not completely filled or the material was not melted at that point. For any pressure greater than zero at the entrance to the metering section, the pressure drop across the metering section will not be the same as the reading of the gauge in the head and the output rate will be different from that predicted by using the head pressure in equation (1). This is the normal case in a well designed extruder. In fact, as will be shown, pressures considerably higher than the head pressure can be developed before entrance to the metering section. This results in a forward pressure flow through the metering section and an output rate greater than the theoretical pumping capacity.

Experimental Equipment

Pressure profiles along the barrel of a 2.5″ extruder have been determined in the equipment shown in *Figure 1*. This extruder has five pressure gauges spaced at 9″ intervals. The first gauge is about 20″ from the front of the feed hopper. The last one is located in the adaptor section at the end of the screw. An immersion type melt thermocouple is also located at this position. The machine has two removable 9″ sections, giving length to diameter ratios, measured from the front of the feed hopper, of 15.0, 18.6 and 22.2 to 1. One of the removable sections contains provisions for venting. A needle type pressure control valve and ¼″ diameter rod die are shown mounted on the head adaptor. The extruder is equipped with a 50 HP Dynamatic drive and, by means of pulley changes, can be operated at top speeds of 175, 350 or 450 RPM.

Metering type screws of the three basic lengths are shown standing behind the machine in *Figure 1* and, schematically, in *Figure 2*. These screws all have the same channel depth at the feed hopper (0.450″) and the same depth (0.094″) in a four turn metering section. They differ only in the length of the increasing-root-diameter transition section. Also shown in *Figure 2* is a two stage screw designed for venting, but application of this screw for that purpose will not be discussed in this paper.

Experimental Results

Typical pressure profiles for the 22/1 L/D screw, operated with BAKELITE polyethylene resin DYNH (0.918 density, 1.6 melt index) at a uniform barrel temperature of 180 C, are shown in *Figure 3*. Curve 1 was obtained with the valve in its wide open position. Curves 2, 3 and 4 were obtained by successively closing the valve to give higher head pressures. Pressure peaks well back in the barrel

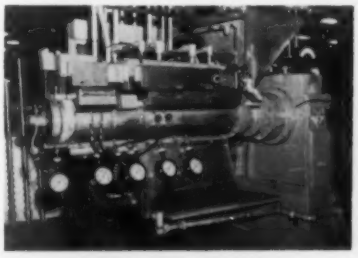


Figure 1. 2.5″ Extruder.

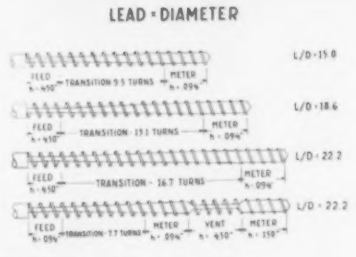


Figure 2. Extruder Screws.

This article adapted from a paper presented at the 16th ANTEC—Chicago—January, 1960.

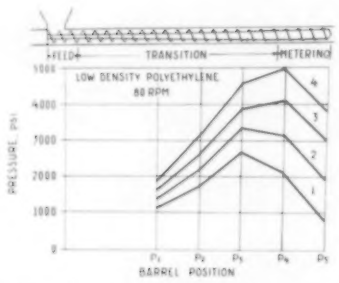


Figure 3. Typical Pressure Profiles.

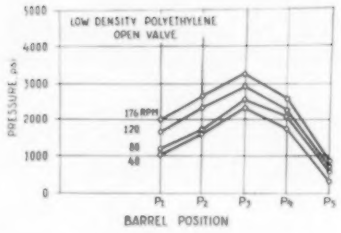


Figure 4. Effect of Screw Speed.

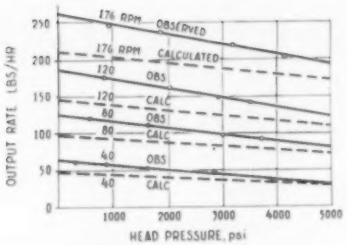


Figure 5. Observed Versus Calculated Output Rate.

are noted in all cases. It is also noted that fluxing occurs prior to position P_1 in all cases. Raising the head pressure forces the fluxing point further toward the rear of the machine and the location of the pressure peak further toward the exit end.

Changing the screw speed does not alter the basic shape of the pressure profile, as seen for the low head pressure (open valve) condition in *Figure 4*. Similar results were obtained at higher head pressures.

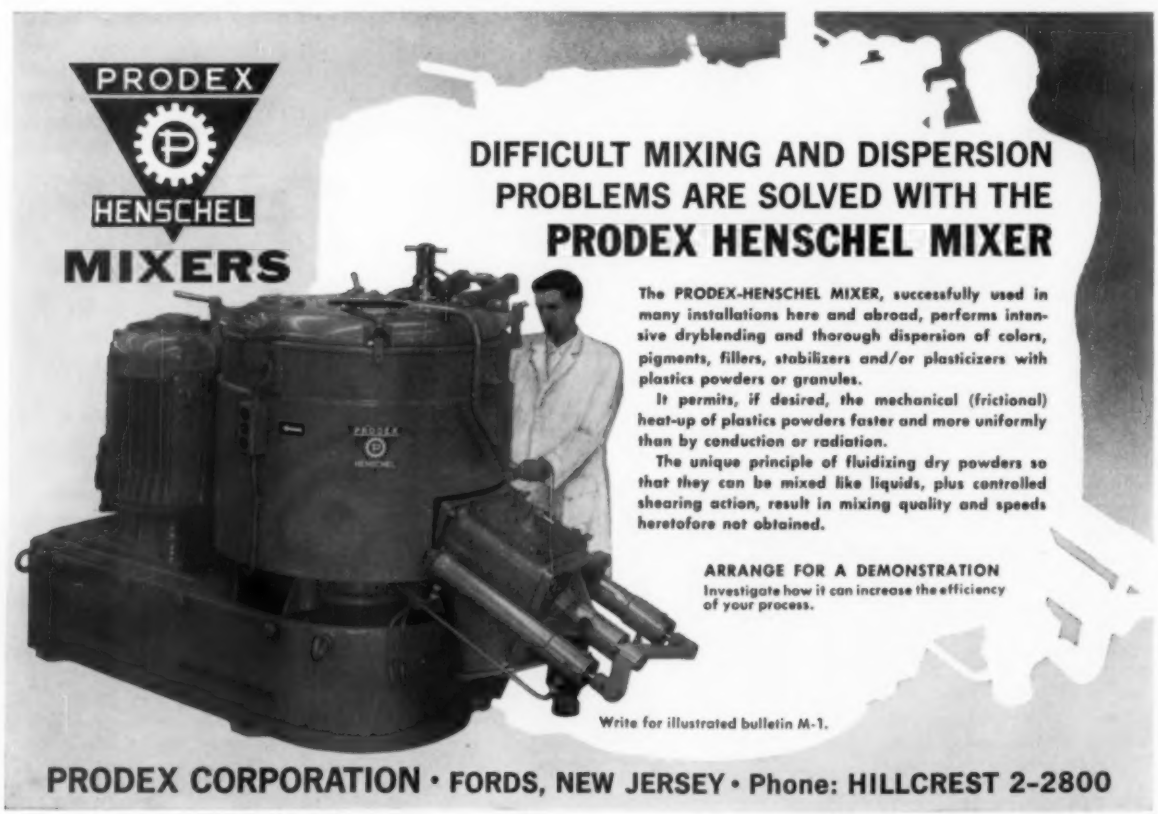
Observed and calculated rate vs. pressure curves are shown in *Figure 5*. The higher-than-predicted output rates are due to the pressure peak near or back of the entrance to the metering section (*Figures 3 and 4*). The output is actually controlled from a point in the vicinity of the pressure peak, where the channel depth may be greater than in the metering section, and there is a forward pressure flow through the metering section. The metering section thus acts as a restriction to flow in the same manner as a valve or die. This does not detract from its primary function of metering and dampening of pulsations.

Effect of Barrel Temperature

Anything which affects the magnitude or stability of the pressure peak will, obviously, affect the output rate. Changing the barrel temperature gradient had very little effect with low density polyethylene. However, this had a major effect with certain other materials.

Results with a high molecular weight polystyrene (BAKELITE SMN-5401 Crystal 11) are shown in *Figure 5*. The pressure profile with a uniform barrel temperature of 180°C is shown in the center graph. Lowering the rear barrel temperature to 120°C (top graph), raised the pressure peak, due to a higher melt viscosity at this lower temperature condition, and increased the output rate about 20%. Raising the rear barrel temperature to 240°C (bottom graph) lowered the peak pressure, as a result of the reduced viscosity, with a corresponding reduction in output rate.

Similar effects of barrel temperature gradient are noted in *Figure 6* for a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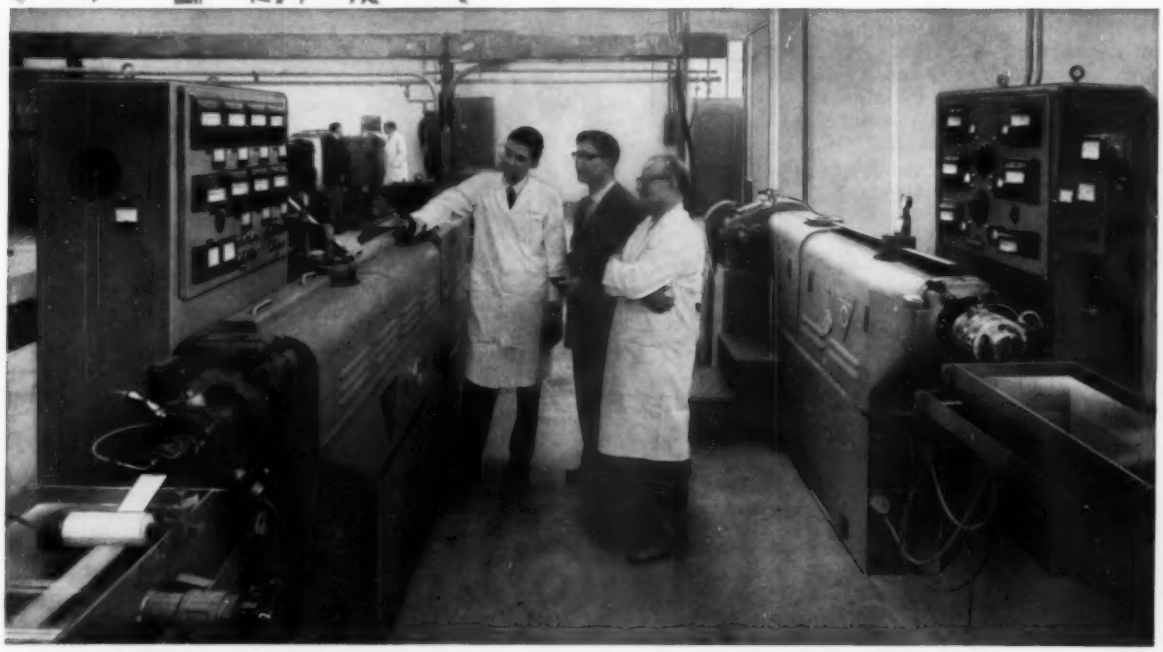

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high molecular weight polystyrene and, in *Figure 7*, for a high impact polystyrene. *Figure 8* shows effect of barrel temperature gradient for a plasticized, 70 Durometer, vinyl compound (BAKELITE VFD-9970 White). The highest pressure peak was observed with a rigid (unplasticized) vinyl compound (BAKELITE VGGB-3001 Clear), *Figure 9*, due to the extremely high melt viscosity of this type of material.

Reverse effects of barrel temperature gradient were noted with high density polyethylene (BAKELITE DGDD-4100, Natural, 0.95 density, 0.3 MI). This is illustrated in *Figure 10* where it is seen that higher pressure peaks and output rates were obtained by raising the rear barrel temperature. This type of material, due to the hardness of the granules and the relatively high, sharp melting point, is dependent, to a considerable extent, upon conducted heat for initial warm up in the rear section of the machine. The rate of melting is therefore a function of the barrel temperature in this area and the particles are not readily deformed by frictional working until their temperature begins to approach the crystal melting point.

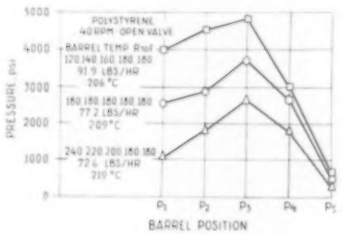

Figure 6. Effect of Barrel Temperature Gradient with Polystyrene.

High density polyethylene is similar to nylon in this regard and it is probable that a modified nylon type screw, having a more rapid transition from the feed depth to the metering depth at the entrance to the metering section, would be more appropriate. This type of screw was not available at the

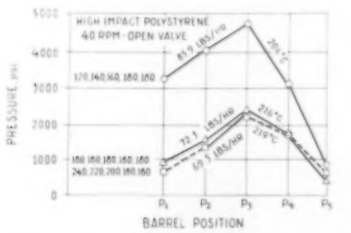

Figure 7. Effect of Barrel Temperature Gradient with High Impact Polystyrene.

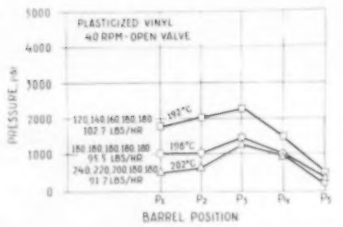

Figure 8. Effect of Barrel Temperature Gradient with Plasticized Vinyl Compound.

time these experiments were run, but subsequent experience has shown this to be the case.

Two Stage Screw

Operation with the two stage screw of *Figure 1* is shown in *Figure 11* for

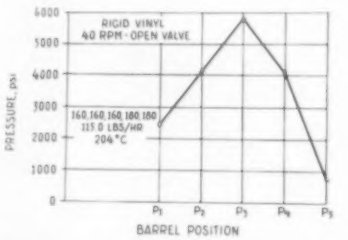

Figure 9. Pressure Profile with Rigid Vinyl Compound.

1.6 MI, low density polyethylene at a uniform barrel temperature of 180C. The vent port in the barrel was plugged in this case. Comparing the pressure profiles for this screw with those of *Figure 3* for the single stage screw, it is seen that the pressure peaks back of the exit metering section have been eliminated. At low discharge pressure (Curve 1—open valve), the screw flight in the vent area is not completely filled and the pressure in this area (P_3) is zero. There is a small pressure peak back of the first stage metering section, however. At high discharge pressures (Curves 3 and 4), the vent section is completely filled and the pressure increases continuously over the length of the barrel.

The output rate with two stage screws operated at a low head pressure is controlled by the first stage metering section. This is illustrated in *Figure 12* where observed and calculated second stage output rates are plotted against head pressure. The calculated open discharge rate for the first stage metering section was 96.4 lbs./hr. This was essentially the output obtained from the second stage at all head pressures up to about 2000 psi. Above this pressure, the vent section is completely filled and under pressure and the second stage begins to assume control. The rate thereafter decreases, with further increases in head pressure, along a curve approximating the calculated characteristic of the second stage.

Effect of Screw Length

Pressure profiles obtained with the three single stage screws of 15.0, 18.6 and 22.2 L/D ratios, and the 22.2/1 two stage screw are shown in *Figure 13*. These data were obtained at 80 rpm during extrusion of film from a mixture of natural and red pigmented, 1.6 MI, low density polyethylenes at a barrel temperature of 150C. Quality of mixing, indicated by film roughness and color streaking, was also measurable by this means. The numbers on the curves are visual quality ratings for the extruded film where number 1 is excellent and number 7 is very poor. A quality of 3, as obtained with the two stage screw, is considered a minimum level of commercial acceptance.

Satisfactory film quality was not obtained with any of the single stage screws under the low head pressure

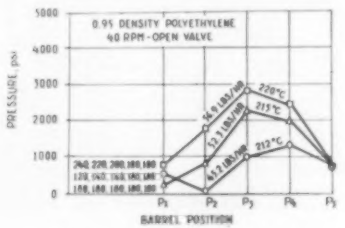

Figure 10. Effect of Barrel Temperature Gradient with High Density Polyethylene.

condition (open valve) of *Figure 13*, but the two stage screw did give an acceptable product under this condition. Raising the head pressure to improve the degree of mixing produced

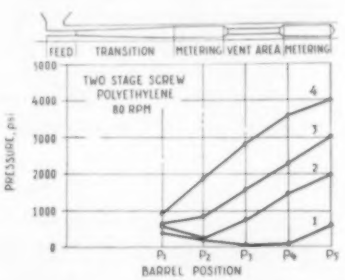

Figure 11. Pressure Profiles with Two Stage Screw.

the results shown in *Figure 14*. Pressures of 3500 to 4000 psi were required for minimum acceptability with the conventional screws, while the two stage screw gave equivalent or better mixing and a higher output rate at a pressure of only 2000 psi. The improved mixing with the two stage screw is attributed to changes in flow pattern taking place in the deep channel vent area (vent port plugged). While this subject has not been explored in detail, these results suggest that mixing might be further improved by a series of deep and shallow channel sections in the forward end of the screw. More will be said on this subject later.

Other effects of length to diameter ratio are illustrated in *Figures 15* and *16*. Increasing the L/D ratio decreases the slope of the rate vs. pressure curve, *Figure 15*. This is also related to the location of the pressure peak and, in effect, is equivalent to increasing the length of the metering section.

Mixing quality ratings are also shown in *Figure 15*. The 15.0 L/D screw, whose output rate is most affected by pressure, also shows the greatest effect of pressure on mixing efficiency. While it is possible to achieve good mixing with the shorter screws, it is seen that this is only at the expense of output rate. Comparing the screws at equal output rates, the longer screws give better mixing, although higher pressures are necessary to achieve this effect.

Power consumption and frictional heat development also increase with increasing L/D ratio. This is reflected in the extrudate temperature. A typical example, as a function of head pressure at 80 rpm, is shown in *Figure 16*. Frictional working and stock temperatures are lower with the shorter screws at low head pressure but increase more rapidly with increasing pressure. This correlates with the effects of pressure on output rate and mixing as discussed above in reference to *Figure 15*.

Summarizing, the primary result of an increase in L/D ratio is an increase in effective length of the metering section and a greater length and volume of fluxed material in the channel. This reduces the pressure sensitivity with respect both to output rate and frictional heat generation, resulting in a higher output rate at high

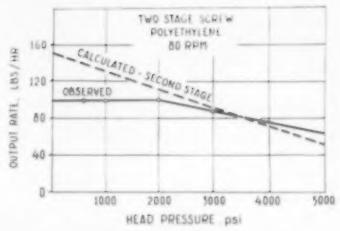

Figure 12. Output Rate with Two Stage Screw

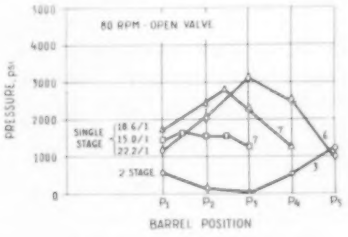

Figure 13. Comparison of Screws at Low Head Pressure.

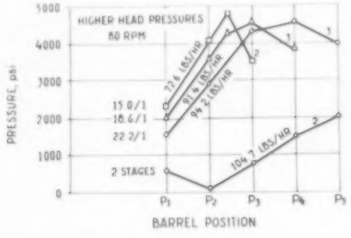

Figure 14. Comparison of Screws at Higher Head Pressures.

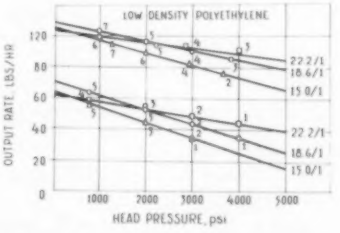

Figure 15. Effect of L/D Ratio on Output Rate at 40 and 80 RPM.

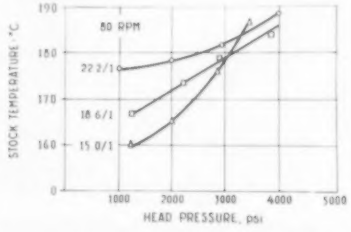

Figure 16. Effect of L/D Ratio on Stock Temperature.

pressures, a higher stock temperature at low pressures and better mixing at a given output rate. Similar effects would be produced by increasing the length of the metering section up to a point where melting capacity would begin to limit the output rate.

Additional Studies

Experiments conducted since this paper was submitted have shed additional light in some of these areas. It was concluded in the original work, for example, that the improved mixing achieved in the two stage screw could be attributed to changes in flow pattern taking place in the deep channel vent area. While this is still considered a contributing factor, there is now reason to believe that the additional metering length, as represented by the second stage metering section, may also have been a significant factor.

The two stage screw was eventually cut off at the end of the first metering section, a new length welded on and machined to the same channel dimensions as the first metering stage. This gave a 22/1 L/D screw having a feed depth of 0.450″, a 7.7 turn transition section and a 13 turn metering section with a channel depth of 0.094″. Initial trials showed that this screw tended to generate too much frictional heat so the metering depth was finally increased to 0.110″. These two modifications are compared with the conventional 4 turn metering screw in *Figures 17 through 21*.

The effects of metering length and depth on output rate and product quality are shown in *Figure 17*, again for extrusion of 0.92 density polyethylene film. Increasing the metering length from 4 turns to 13 turns at a depth of 0.094″ lowered the output rate about 25% and improved the degree of mixing very markedly. The stock temperature was increased about 30°C (54°F), however. Increasing the depth of the long metering section to 0.110″ gave intermediate levels of rate, temperature and quality.

Stock temperature versus screw speed is shown for the open valve condition in *Figure 18*. The two 0.094″ depth screws show a significant increase in stock temperature with increasing screw speed, while the deeper (0.110″), long metering screw is somewhat less sensitive in this respect. In fact, the temperature tended to level off with this screw at the higher

screw speeds, a very desirable effect. At higher head pressures, these curves are all displaced upward about 5°C for each 1000 psi increase in pressure.

Output rate and quality versus pressure at 160 RPM are shown for the two 13 turn metering screws in *Figure 19*. It is seen that good mixing was achieved at rates on the order of 180 lbs./hr. and pressures of 2000-3500 psi. Data for the 4 turn metering screw are not included because it was not possible to obtain good mixing under any condition at this screw speed.

The superior results obtained with the long metering screws at speeds up to 160 RPM indicated that it should be possible to operate such screws at still higher speeds. The 0.110" depth screw has recently been operated at 280 RPM, giving excellent quality at 320 lbs./hr. with a head pressure of about 4000 psi.

It was noted in *Figure 17* that the output rate is lowered by increasing the length of the metering section. This is caused by elimination of the peak in the pressure profile. Pressure profiles for the 4 turn–0.094" depth and the 13 turn–0.110" depth screws are shown in *Figure 20*. The solid lines are for the open valve condition where the characteristic pressure peak with the short metering section is completely lacking with the long metering section, while the quality level with the longer metering screw is considerably better. At higher head pressures (dotted lines–3000 psi), the pressure increases continuously with the longer metering screw and the quality, again, is markedly improved. The long metering section acts as a true metering pump and an output rate very close to the theoretical pumping capacity is obtained.

Further evidence of the improved product uniformity obtained with long metering sections is illustrated in *Figure 21*. This is a tracing from a recorder chart showing the stock temperature as measured by the melt thermocouple in the head cavity near the tip of the screw. Rapid temperature fluctuations of about ± 10°C (18°F) are observed with the 4 turn metering screw under this condition (120 RPM—open valve), whereas the temperature with the 13 turn metering section remains essentially constant. Such temperature fluctuations always accompany a condition of poor mixing. They are usually reduced and frequently eliminated by raising the head pressure. They were not completely eliminated with the short metering screw at 6000 psi and the quality at this higher pressure was still poor.

A recording of stock temperature gives an excellent indication as to whether an extruder is operating under optimum mixing conditions and its use for this purpose is strongly recommended.

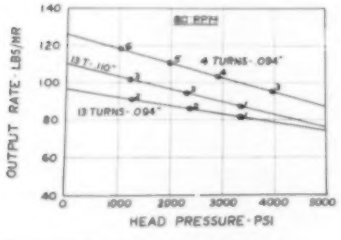

Figure 17. Effect of Metering Length and Depth on Output Rate and Product Quality.

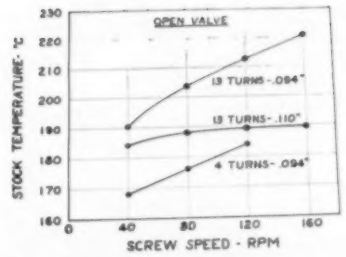

Figure 18. Effect of Metering Length and Depth on Stock Temperature.

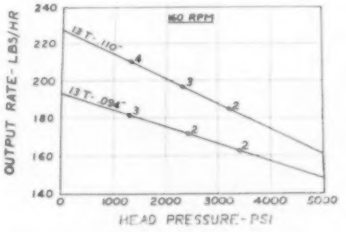

Figure 19. Output Rate and Quality at 160 RPM.

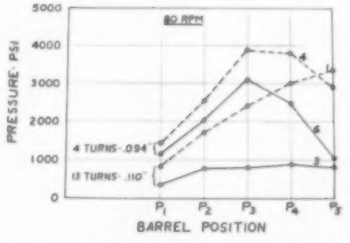

Figure 20. Pressure Peaks Not Observed with Long Metering Sections.

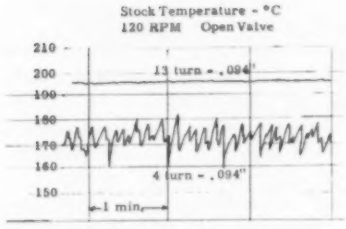

Figure 21. Extreme Stock Temperature Fluctuations Noted with Short Metering Section.

Conclusions

It is now felt that major improvements in product quality at high output rates can be achieved by increasing the length of metering sections considerably beyond those normally employed in present day screw designs. Obviously, there will be some limiting length beyond which the melting capacity of the feed and transition sections will become the controlling factor. This will depend upon the material type and certain operating conditions. For low density polyethylenes and non-crystalline polymers which do not have sharp melting points, it is believed that a 20/1 L/D extruder could advantageously devote at least half of its total length to metering section. It is further believed that this approach offers a practical method for achieving quality production at higher screw speeds and output rates wherever higher stock temperatures can be tolerated.

The problem of attaining a high output rate at a low stock temperature is not resolved by this method and it is felt that this is one area in which future development effort should be concentrated.

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2. "How to Predict Extruder Performance with Polyethylene", B. H. Maddock, *Plastics Technology*, May, 1957.

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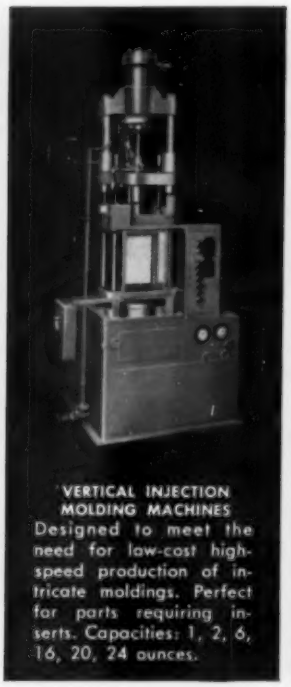

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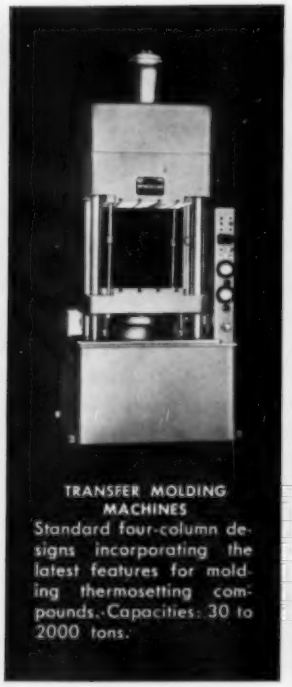

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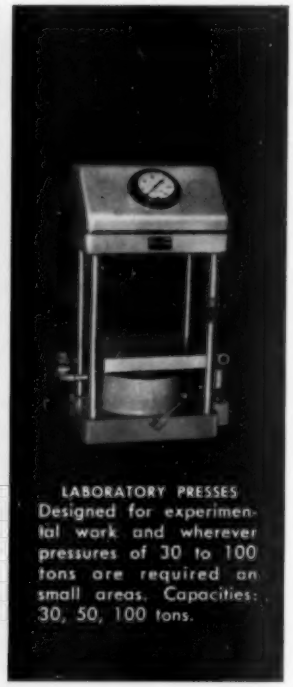

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When you come to Watson-Stillman you get far more than machinery: You get experience that exactly parallels the history of the plastics industry.

Watson-Stillman engineers know your industry and its processes. From the company's "Complete-line" of equipment they can prescribe a machine that is right for the job. And, because Watson-Stillman makes all types, recommendations are made without bias.

Remember: The line features both standard and special machines—in a broad range of sizes and capacities. Modern design features assure high output at low cost.

Ask for details on any of the machines shown on this page.

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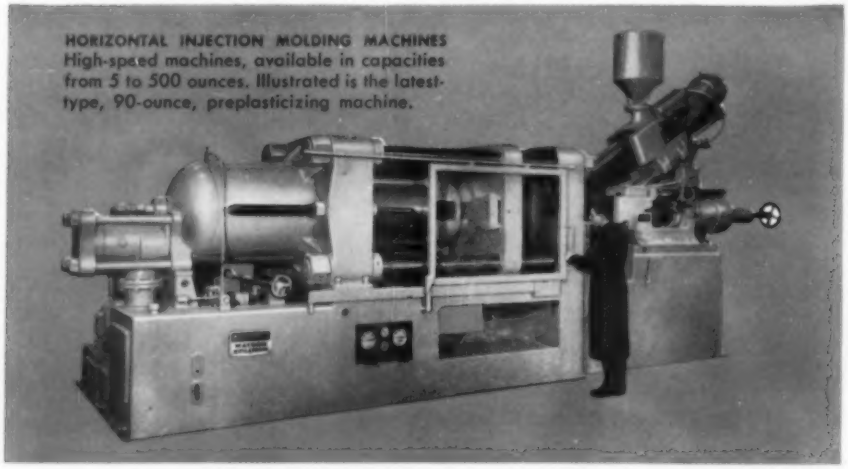

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High-speed machines, available in capacities from 5 to 500 ounces. Illustrated is the latest-type, 90-ounce, preplasticizing machine.

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Watson-Stillman also manufactures compression molding presses, hobbing and die-sinking presses, laminating and polishing presses, and presses for special requirements.

WS-74

Here's vinyl film so crystal-clear it *flatters* the fruit. So tough to tear that handling and shipping don't faze it.

The Clopay Corporation makes it out of Diamond PVC 450 resin and calls it *Clopane*. Cobb Fruit and Preserving Company buys it by the mile. So do other sales-wise packers. Easy to see *why*.

The special properties of Diamond PVC 450 (U. L. approved)—rapid plasticizer absorption, clarity and freedom from gel particles—can do wonders for dry-blend extrusions, calendered film and sheeting, wire insulations.

We'd be glad to discuss PVC 450 in terms of *your* exact needs. Write Diamond Alkali Company, 300 Union Commerce Building, Cleveland 14, Ohio.

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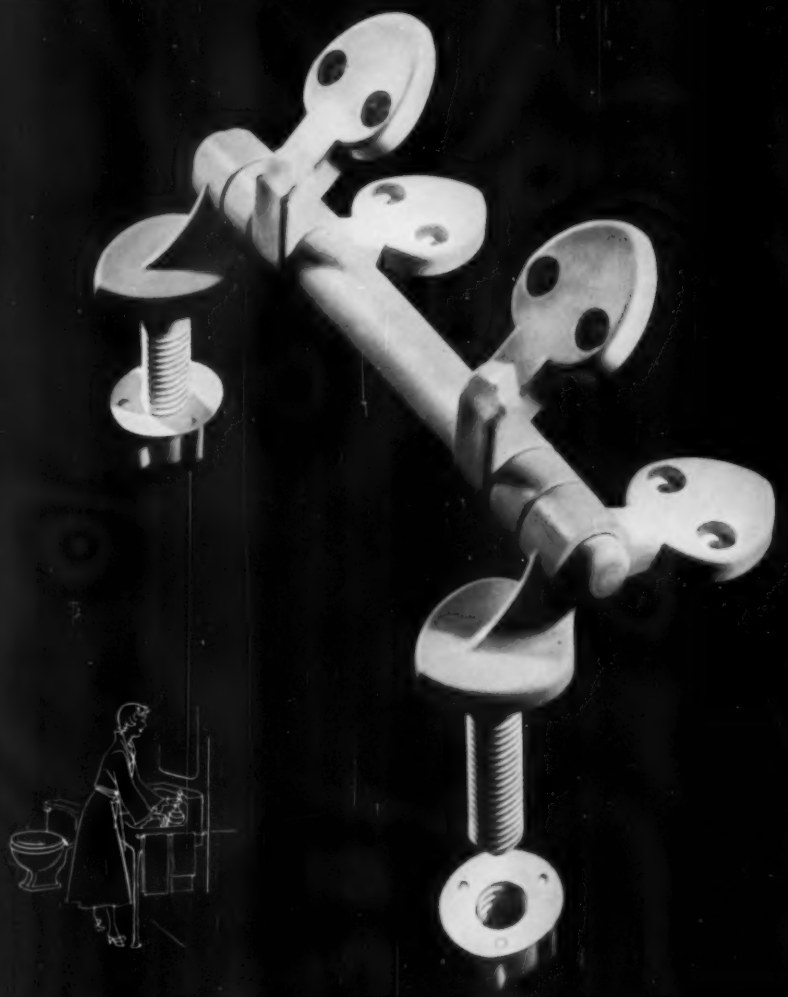

Hinge for Century seat eliminates metal

The Century hinge is designed for long, trouble-free service. It is an important quality feature of the deluxe toilet seat design. Molded of Fortiflex linear polyethylene, *the hinge has no metal parts . . .* is corrosion-free and can be cleaned with boiling water. It has a smooth, lustrous surface that is mildew proof. The low coefficient of friction of the material makes the hinge "self-lubricating."

Fortiflex is an easily molded, tough, rigid design material. An economical plastic, it can often replace metals and other materials in your design, with savings.

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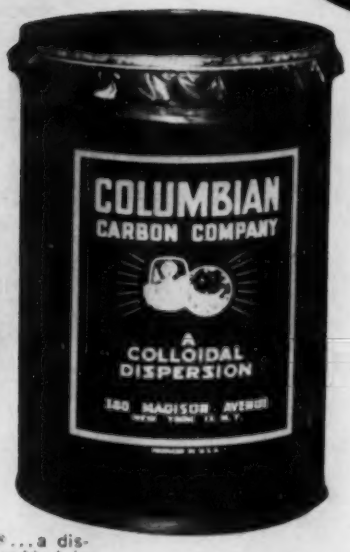
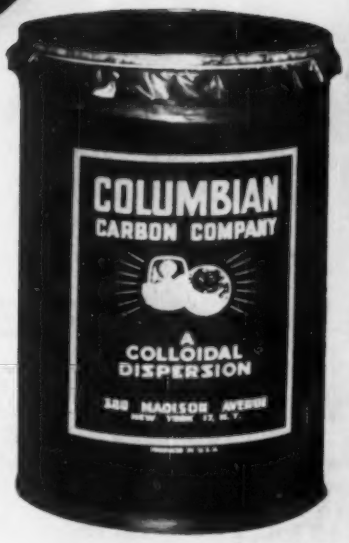


COVINYLBLAK®...a dispersion of carbon black in vinyl resin—chip form.

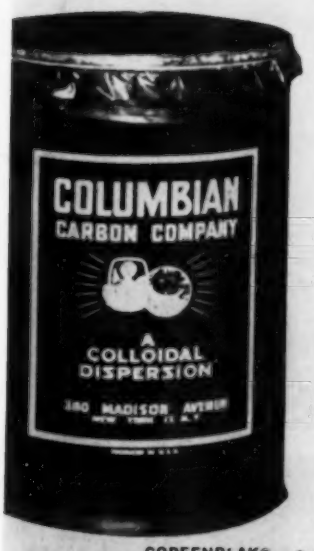


COSTYRENEBLAK®...high quality colloidal dispersions of carbon black in polystyrene resin—concentrated granular form.

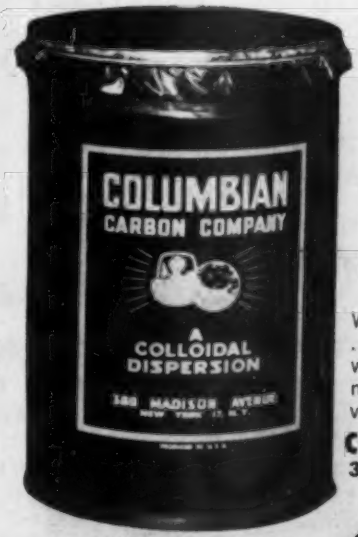
COLUMBIAN...

outstanding carbon black dispersions for plastics

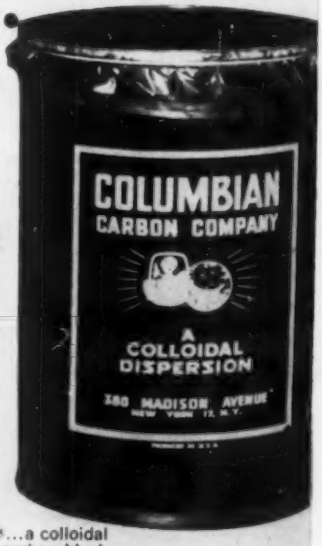
every step of the way!



COPEENBLAK®...a colloidal dispersion of carbon black in polyethylene resin—concentrated form.



AQUABLAKS®...water dispersions of carbon black for integral dyeing of synthetic fibers.



COWAXBLAK®...a colloidal dispersion of carbon black in chlorinated paraffin—chip form.

Whatever your need in the plastics industry ...Columbian's predispersed carbon blacks will meet your most exacting requirements efficiently and economically...provide unsurpassed quality...and profit!

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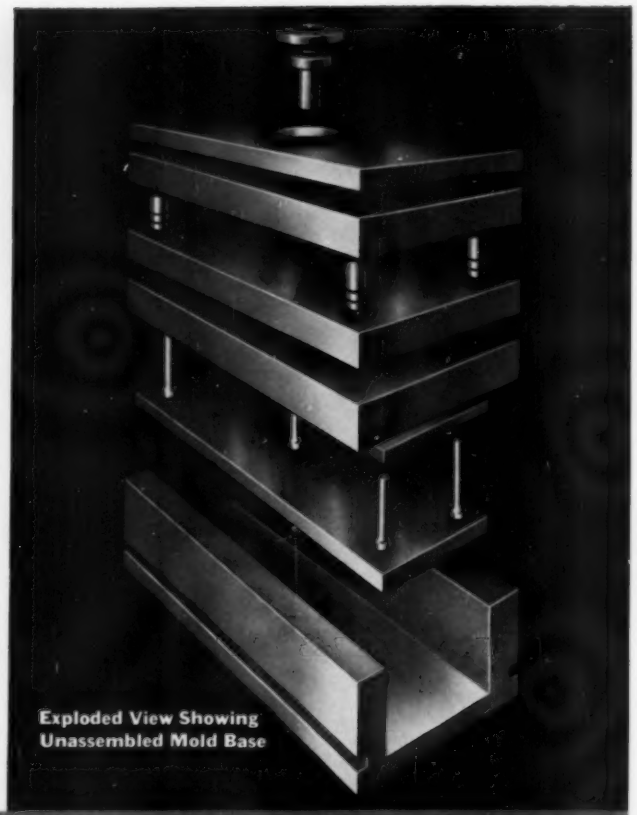
3 WAY SAVINGS

WITH D-M-E STANDARD MOLD BASES



Exploded View Showing Unassembled Mold Base

1 GREATER ECONOMY

Interchangeability lets you replace *any* component without special fitting or reworking. When you replace a cavity plate (regardless of thickness), leader pins and bushings will be in alignment every time! What's more, you can select from over 7,000 cataloged Mold Base combinations.

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Delivery from local stock means you get Standard Mold Bases, components and moldmakers' supplies when you need them—direct from D-M-E's fully-stocked local branches!

3 ADDED QUALITY

Exclusive design and construction features at standard prices: First-quality steel; surfaces ground flat and square; patented tubular dowel construction; one-piece ejector housing; stop pins welded to ejector bar; and sizes to 23¾" x 35½"!

ARE YOU GETTING THE NEWS?

D-M-E's monthly publication is full of cost-saving ideas for designers, moldmakers and molders. Write on your letterhead—we'll place your name on the "NEWS" mailing list. No cost, no obligation.

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R. T. O'Connor and H. J. White

Devcon Plastic Steel Corp.

MOLDMAKING

A Heat Conductive Epoxy-Aluminum Formulation for Low Cost Molds

The material is easy to use, machines as good as or better than most metals, is capable of withstanding temperatures as high as 400°F. continuously, has high strength retention at these elevated temperatures, and exhibits low shrinkage. It is a casting material which when heated and mixed with the hardening agent can be poured over a model and oven-cured to produce a fully cured mold.

Devcon Corporation recently introduced a material called Devcon C which has been used for the manufacture of low cost plastic, rubber, and vacuum forming molds.

The material is composed of 80% aluminum and 20% epoxy resin. It requires an elevated temperature cure to obtain maximum physical properties. Devcon C has been primarily used for prototype and development applications.

One of the major factors limiting its use in long run applications is the low thermal conductivity and resulting long molding cycles. This paper will discuss methods of increasing thermal conductivity that we have investigated.

The following systems were studied:

a. Embedment of copper heating or cooling coils in the mold.

b. Incorporating wire screening in the mold.

c. Filling the casting material with copper aluminum fibers.

Two types of copper tubing were investigated, ¼ in. OD and ⅜ in. OD. The ¼ in. OD copper tubing was not satisfactory because of the small surface area available. We were not able to incorporate a sufficient amount of this tubing in the casting to obtain efficient working properties. The ⅜ in. OD copper tubing with a .030 in. wall thickness was better, and in many cases was sufficient. It is necessary, however, to incorporate a fairly complicated network of tubing in the casting to obtain the desired results. The use of this tubing is a good answer to our problem. However, by improving the thermal conductivity of the casting material itself, an even more efficient mold can be obtained.

Investigation of wire screening did not produce uniform results. It was difficult to place layers of wire screening close enough to the surface of the cavity to obtain efficient heat transfer. The problem was particularly difficult when intricate models were used. Long set up times were required to suspend the wire screening in place and to affix it in such a way that no movement would occur while casting and curing the resin. If the wire screening is not fixed in place properly, it will float to the outside surface and its effect is lost. Because of the impractical casting difficulties, the thermal conductivity or other properties of such systems were not investigated.

Initial work with copper-aluminum fibers showed two things:

1. the fibers were easily incorporated in a resin system

2. the heat transfer properties appeared to be increased considerably

Physical Properties of Devcon C @ 70°F.

(cured for 5 hrs. at 250°F. and 10 hrs. at 320°F.)

Compression Strength	30,000 psi
Tensile Strength	9,000 psi
Flexural Strength	19,000 psi
Coef. of Thermal Expansion	0.000045 cm/cm/°C.
Flexural Deformation Temp.	402°F.

Test Results in Tabular Form—Conductivity Measurements

Specimen	Casting Method	% Resin by wt.	% Devcon C by wt.	% Fiber by wt.	Weight Loss 5 days at 180°C.	Weight Loss 4 days at 225°C.	Heat Distortion Temp. (ASTM-DG48-56)	Thermal Conductivity (Cenco Fitch Method)
1.	slurry	100	—	—	—0.48%	—18.2%	200°C.	3.3 x 10-4
2.	slurry	—	100	—	—0.21	— 9.5	200°C.	13.9 x 10-4
3.	sprinkled	77	—	23	—0.22	—11.5		10.5 x 10-4
4.	sprinkled	72	—	28	—0.24	— 6.5		12.2 x 10-4
5.	slurry	—	83	17	—0.22	— 6.4		20.6 x 10-4
6.	slurry	—	80	20	—	—	206°C.	16.6 x 10-4
7.	slurry	—	68	32	—0.06	— 6.4	206°C.	37.4 x 10-4
8.	sprinkled	—	78	12	—0.15	— 8.0		21.2 x 10-4
9.	sprinkled	—	76	14	—	—		21.4 x 10-4
10.	sprinkled	—	87	17	—0.11	— 9.8		30.6 x 10-4
11.	sprinkled	—	75	25	—0.04	— 6.3		26.0 x 10-4
12.	Pressure cast and gelled at 300 p.s.i.	45	—	55	—	— 5.9		23.0 x 10-3
13.	Pressure cast and gelled at 300 p.s.i.	—	62	38	—	— 7.2		49.3 x 10-3

For these reasons a study of copper aluminum fibers in two resin systems was conducted. The two resin systems used were (1) an epoxy resin based on epichlorohydrin and bisphenol A with an epoxide value of 190 grams/equivalent of epoxy group. This was cured with an anhydride with a cure schedule of 5 hrs. at 120°C. followed by 12 hrs. at 160°C and (2) Devcon C, which has been briefly described above, and cured at 120°C. for 5 hrs. followed by 12 hrs. at 160°C. Three methods of incorporating the fibers were evaluated:

A. Sprinkle method—specimens prepared by this method were made in an open preheated mold. A layer of resin was brushed on the bottom surface of the mold and a layer of fibers was sprinkled over it. The specimens were built up by adding successive layers of resin and fibers to a thickness of ⅛ inch. The mold was then placed in an oven to undergo the above cure schedule.

B. Slurry casting method—specimens prepared by this method were made in an open preheated mold. The resin and fibers were premixed at 100°C. followed by addition of the hardening agent to the resin-fiber mix. The resin-fiber mix was cast into the open mold and cured.

C. Pressure cast method—specimens prepared by this method were gelled under heat and pressure. The resin, fibers and hardener were mixed as in method two and cast into an open preheated mold. The mold was then placed in a Carver laboratory press and pressure was exerted by a plunger. This plunger was vented to allow excess resin to escape from the casting. A force of 300 psi was applied. Constant pressure was applied, and a temperature of 120°C. was maintained for two hours by which time the specimen had gelled. The specimen was then placed in an oven to undergo the above cure schedule.

Formulation #7 contains about the maximum amount of fibers that can be incorporated in a Devcon C system without using pressure. If more fibers are used, they will not be wet out completely.

The results of thermal conductivity measurements listed in the Tabular results show the following:

- A comparison of specimens 1 and 2 shows that the conductivity of Devcon C, an aluminum filled system, is four times that of the unfilled resin.
- In cases where resin was used as a binder, a lower conductivity was obtained than when Devcon C was used. Compare, for example, specimen 4 a resin based casting containing 28% fibers with specimens 8 and 9 (Devcon C based castings containing 12 and 14% fibers) respectively. The conductivity of the Devcon based castings is twice as great.
- There is no noticeable difference between the slurry cast and the sprinkle method of making the casting.
- Specimen 7, a highly filled casting, gives a ten fold increase in conductivity over specimen 1.
- In general an increase in the amount of fibers results in an increase in the thermal conductivity as would be expected.
- Casting under pressure results in a large increase in thermal conductivity as shown by specimens 12 and 13. This increase is due to two factors; the ability to incorporate more fibers, and the denser packing of the fibers. The second factor is definitely the more important as is seen by comparing specimens 13 and 7. These have approximately the same fiber content, yet the conductivity is increased 12 times in the pressure cast specimen.
- Again a comparison of specimens 12 and 13 show the Devcon based casting has a greater conductivity than the resin based even though a smaller percentage of fibers is used.

—— ■ ——

edited by **E. Paggi,**
Newark Die Co.

U.S.I. POLYETHYLENE NEWS

A series of advertisements for plastics and packaging executives by the makers of PETROTHENE® polyethylene resins

Packaging Notes

A new polyethylene pouch-in-carton has been adopted by a west coast food concern for packaging frozen fruits in syrup. According to company officials the new container saves 35% over previous packaging costs for lithographed composite fiber-metal containers.

The package consists of a 2.75-mil heat-sealed polyethylene pouch inside a standard lock-tab folding carton with overwrap. The firm reportedly uses a continuous pouch forming-filling-sealing machine which turns out 3,000 pouches per hour.

Retailers are said to like the conventional size and shape of the overwrapped packages. Consumers like the fast, leakproof thawing and ease of opening offered by the new frozen food container. Thawing time for the pouch pack is said to be only 9½ min. in 100°F. water, as compared with 45 min. for conventional fiber containers.

Now, scented polyethylene for packaging, molded items: a new dimension—aroma—has been added to polyethylene packaging films and molded items. Crystal-clear polyethylene films now can be made to create packages that pleasantly affect the senses of both sight and smell. This added sensory dimension is expected to stimulate sales still further for items packaged in polyethylene.

A wide variety of scents have already been developed, including such aromas as "clean linen" for fresh laundry packages, perfume for packaging women's lingerie, sweaters, handkerchiefs, and stockings, and lavender, tweed, cedar, pine, and spruce for men's sport clothing packages. Other aromas such as "cookie", "baked goods", spearmint, chocolate, lemon, orange, and lime will be offered by the manufacturer in the future, pending F.D.A. approval.

The fragrances are sold in the form of polyethylene/scent concentrates, which are dry blended with U.S.I. PETROTHENE film grade resin in making scented film. Between ¼ and 2% of scented polyethylene concentrate is used, depending on the scent. The manufacturer of the scent concentrates claims to be able to scent resins of any density or melt index required by the extruder, and that all aromas become an integral part of the polyethylene film—they cannot be washed away.

U.S.I. Opens Polyethylene Housewares Exhibit

An educational exhibit, designed to show retailers and manufacturers how quality polyethylene housewares are made was recently opened by U.S.I. The exhibit is located in the Housewares Building, 1150 Broadway or 230 Fifth Ave., New York City.

Occupying a space in the building's main lobby, the exhibit tells the story of polyethylene from manufacture of quality resin to production of quality goods through modern molding techniques. The display includes photos of plant facilities and samples of fine molded houseware articles.

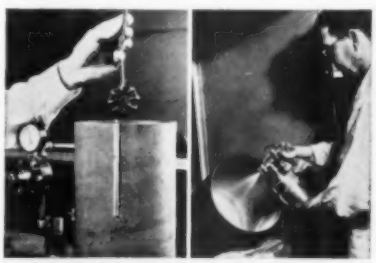
U.S.I. Introduces "MICROTHENE" Finely Divided Polyethylene

Resin in Powder Form Expected to Expand Use of Polyethylene in Textile, Metal and Many Other Fields

Polyethylene in finely divided or powdered form is now being produced by U.S.I. and is available in sample and semi-commercial quantities under the tradename "MICROTHENE". Already in use in Europe, finely divided polyethylene is expected to open many new markets for the resin in this country and to expand a number of existing ones. Some of the applications foreseen include its use in the coating of metal, textile, paper, glass and wood products, as a binder for non-woven fabrics, and as molding powder for production of large polyethylene items such as boats, tanks, and shipping drums.

Methods of Application

In coating operations, MICROTHENE polyethylene can be applied to the substrate in its original powder form, as an organic or aqueous dispersion, or as an organic or aqueous paste. The method selected depends largely on the substrate to be coated, the major requirement being that the substrate be able to withstand the heat necessary to fuse the resin into a continuous coating. In the coating of woven and non-woven fabrics, dry polyethylene powder or a paste is generally spread evenly onto a moving web, which then passes through an oven to sinter the plastic into a film coating. Metal parts can be coated by spraying, dipping, or slush coating with either the dry powder or dispersions. Organic dispersions are generally used on metals that would be corroded by water. With modifications of application techniques, strippable polyethylene metal coatings may be possible.



Two methods for coating metal with MICROTHENE finely divided polyethylene are shown above. Hot object is dipped in fluidized bed of powdered resin, left. Resin dispersed in organic liquid is applied by ordinary spray equipment, right.

Fluidized Bed Technique

Irregularly shaped objects, wire, and other metal items can also be coated with inexpensive equipment employing the fluidized bed technique. The item is first preheated, dipped into a container with the fluidized dry powder, and then cooled or post-heated to achieve a smooth, continuous coating.

Plastic Moldings

Another potential market for MICROTHENE finely divided polyethylene is in the field of large plastic moldings. The powder is poured into heated molds which shape the polyethylene as it melts on the surface of the mold. Excess powder is then poured out. The molds required are extremely simple and inexpensive. Large containers, drums, and even small boats have been made successfully by this technique in Europe.

Two MICROTHENE Resin Types Available

U.S.I. is initially marketing two types of MICROTHENE polyethylene. One type will be similar to PETROTHENE 202 resin (melt index 22, density 0.916); the other type will be similar to PETROTHENE 206 resin (melt index 5, density 0.924). As new market requirements develop, other types of resins will be made available in finely divided form by U.S.I.

Each of the above resins is available in two forms: fine (smaller than 200 mesh) which is made by a solution process; and coarse (50 to 100 mesh) which is made by a mechanical grinding method. Both types of powder will have their own fields of application.

Production Facilities

U.S.I. is now producing MICROTHENE polyethylene at Tuscola, Illinois, site of one of U.S.I.'s two polyethylene plants. The plant, which went on stream in March, has an initial capacity of 2 million pounds per year and is designed for fairly rapid expansion.

Samples of MICROTHENE finely divided polyethylene, and a Technical Data Sheet giving detailed product information may be obtained by writing U. S. Industrial Chemicals Co.

U.S.I. Announces Booklet On Polyethylene Printing

"Printing of Polyethylene" is the title of a new U.S.I. booklet just off the press. It's the latest addition to special U.S.I. literature designed to help achieve finest results with polyethylene packaging film.

The new booklet discusses methods of film treatment, printing techniques, printing inks, and field test procedures. It also contains a glossary of commonly-used ink and printing terms.

A copy of this valuable 16-page booklet is available upon request. Just write to U. S. Industrial Chemicals Co., 99 Park Ave., New York 16, New York.

U.S.I. HELPS IMPROVE CLARITY OF POLYETHYLENE PACKAGING FILM

. . . helps expand your markets for it, too

From shirts to sugar cookies . . . your customers are finding their products look better, sell better when packaged in polyethylene. You can now produce polyethylene film with better clarity than ever before thanks in large part to these U.S.I. research and development services:

FINER RESINS

U.S.I. has developed a number of different PETROTHENE® resins . . . so that you can produce polyethylene film with a complete range of toughness and clarity to suit any end use. These resins are manufactured under rigid quality control conditions to assure resins of the highest uniformity for packaging use. To help you obtain maximum results from these resins, U.S.I. offers literature containing tables and technical information to assist you in choosing the most suitable resin for your particular applications.

NEW PRODUCTION TECHNIQUES

Engineers at U.S.I. are constantly seeking methods for producing better films with PETROTHENE resins. The clearest polyethylene film available today is made by a chill-roll casting process which U.S.I. pioneered. Cast film offers unprecedented clarity and gloss without sacrificing needed strength. Since its development, the process has sparked many new uses for polyethylene film.

U.S.I. has also contributed to higher clarity in blown tubular film with a new annealing chamber technique for film extrusion. When properly used, the technique produces blown film of markedly improved clarity, with practically no impairment of other physical properties.

TECHNICAL ASSISTANCE

A Polymer Service Laboratory is maintained by U.S.I. to help extruders solve production and processing problems. Experienced Technical Service Engineers will be glad to work closely with you on evaluating new resins and assist you in any processing problems. This service is confidential and without obligation.

A wealth of technical literature is also available from U.S.I. to help you take full advantage of the quality of PETROTHENE resins. These booklets cover many phases of processing and use of polyethylene and are available upon request.

ADVERTISING AND SALES PROMOTION

U.S.I. conducts a coordinated advertising and sales promotion program which is designed to help build markets for your polyethylene products. Advertisements directed to *your* customers and prospects appear in leading magazines in the baking, produce, candy, dairy, apparel and food fields. Other U.S.I. polyethylene packaging literature reaches film users and package designers regularly by direct mail.

U.S.I. ads appear in leading magazines to help build your markets for polyethylene film.

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- **Smooth surfaces in metal castings**
- **Plastic in luggage pods**
- **Fast facts on phenolics**

Inside story

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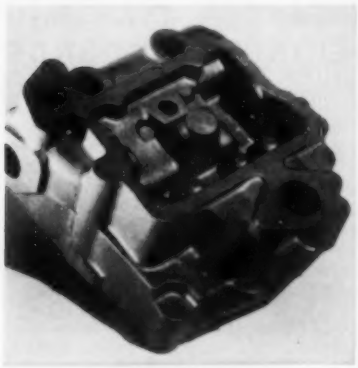

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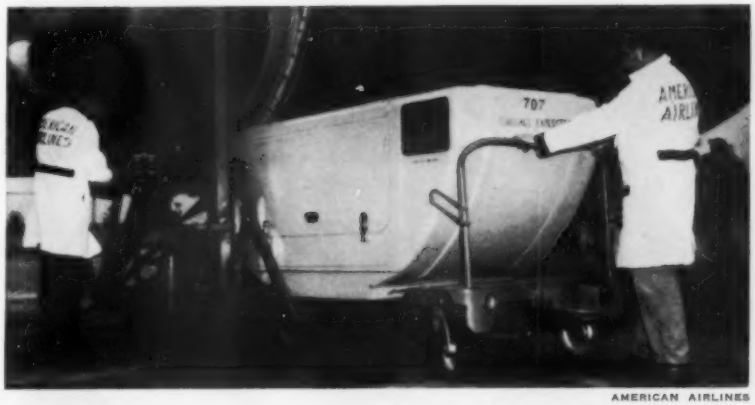

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STANDARDS FOR PLASTICS

Standards For Plastics Building Products

How to make best use of plastics is one of the most pressing problems facing the building industry today. The interest is keen, not only on the part of materials manufacturers and the fabricators of plastics products, but the building industry is likewise closely scrutinizing these materials in the search for economy and superior performance.

One of the greatest deterrents to the more widespread uses of plastics in building is the lack of a comprehensive set of standards for plastics products that will insure reliable behavior and in which the building industry can have confidence. Such standards and specifications are particularly important for plastics because these materials are largely new and untried. The building industry has long made use of wood, steel, concrete, masonry, glass and other materials and is completely familiar with their properties and limitations; furthermore, comprehensive standards for these materials have long been in existence. By contrast, the building industry knows little about plastics, has no long history of their use, and is therefore even more in need of standards and specifications for plastics products than for the familiar materials.

The problem may be brought into focus by considering housing and, more specifically, the dilemma faced by regulating agencies of all kinds. Code officials are besieged by requests to use plastics parts and have little to guide them. The Federal Housing Administration is a particular case in point. It must try to maintain a position between being too conservative on one hand and too venturesome on the other as it develops its minimum standards for the houses which it insures. The FHA, with the active assistance of the Building Research Advisory Board, has made a special study of plastics as they apply to housing and has concluded that its greatest need is for reliable, comprehensive plastics product standards to guide it in setting its own requirements.

When existing standards are examined, it turns out that many of them are for basic materials. Over the years Committee D-20 on Plastics of ASTM has produced a large volume of standards including specifications and methods of test, but mostly for the basic materials, not for plastics products. Indeed, Committee D-20 has taken the attitude, and quite rightly, that such standards must come first. It has had little time to consider the complex problem of standards for products.

It is true that Commercial Standards are being developed for an increasing number of plastics products for buildings, and to the extent that these cover the situation they are to be welcomed. Frequently only such things as standard dimensions are covered, leaving open big questions respecting control of fabrication processes and the quality of the final product.

A case in point is pipe. There is a great deal of activity in setting up standards for thicknesses and threads. This is essential, of course. Methods of certification that pipe is made of nontoxic materials and therefore safe for potable water are also being worked out. This is also essential. Tests and requirements to cover quality have been recently added to standards for some types of pipe. However, they are not included in all pipe standards and, in some cases, sufficient quality requirements are not yet included. More is needed. FHA must be able to assure itself that the pipe will be long-lasting (20 years is about minimum), will not creep unduly under pressure, will not burst, and that it is made under satisfactorily controlled conditions. It must be sure that vermin, termites, and other organisms will not attack it. Unless suitable standards assuring satisfactory long life are set up, plastics pipe will not be enthusiastically welcomed. The work under way in the SPI Thermoplastic Pipe Division and ASTM Committee D-20 in their joint effort to develop satisfactory pipe standards points the way to a solution of the pipe problem. High quality standards are also needed for such items as window frames, gutters and downspouts, roofing, and the many other products[a] under development for buildings. It is not enough to have good standards covering the basic materials, product standards that reflect methods of fabrication, testing, and control of quality of the end product are also needed. The best material in the world can produce inferior end products if fabrication is improperly carried out.

Progress is being made. However, it is slow. The development of good standards requires time, laboratory work, and controlled service tests by a group of qualified scientists and engineers. ASTM, SPI, and ASA are actively at work, but their progress is limited by the number of qualified men available to do the required work. A thorough mutual education of the plastics products producers, the building industry, and regulatory agencies is needed if workable standards that really cover the requirements are to be produced.

[a] Except for plastic pipe and glass fiber reinforced polyester corrugated structural panels, there is very little work under way to develop standards for plastic building products.

■

Edited by **Frank W. Reinhart,**
National Bureau of Standards

Look for these helpful articles in the APRIL ISSUE of MODERN PLASTICS

The Complexities of Coloring Plastics Processors and compounders can expedite production and promote greater customer satisfaction by choosing the right colorant and the right coloring technique. This article represents the first step in a guided tour through this vast labyrinth that can confound the unwary—the colorant field. What colorants are available for what resins – and, in what forms? What determines a specific choice? When to use pigmented resin, master batching, dry blending? What is the real cost of color? These are some of the problems investigated.

Self-Extinguishing Plastics This is Part 2 of the chart, first published in our November issue and completes the listing of self-extinguishing materials –resins, film, laminates, and sheeting. The accompanying feature summarizes the codes and regulations which the plastics industry faces.

Now—the Plastic Gun Barrel Two years ago, the "big surprise" in the field-and-stream market was the molded nylon rifle stock. Now, a major maker of firearms uses reinforced plastic barrels for a line of shotguns. Fully described are: reasons for the switch from steel—how the barrels are produced.

Vacuum Hopper Extrusion Now, the vacuum hopper provides greater economies and versatility in dry blend extrusion of PVC compounds. Heretofore, porosity and rough surface limited the applications of dry blend extrusion. Now, compounds ranging from Type II rigid, to highly plasticized compounds can be processed successfully.

How to Fabricate Laminates A summary of the latest techniques used in fabricating high pressure and low pressure laminates, including machinery and equipment necessary.

Plus many other interesting "applications" stories

Coming in May:

Alloys, Copolymers, and Blends What has happened with alloys, copolymers, and blends. A review of the latest developments outlines cost and property factors in the use of these materials.

Analyzing Material Costs A simple equation is developed which makes it possible to tell accurately the true cost of processing plastics material.

Spot Tests for Plastics Procedures are presented that permit exact identification of plastics.

1960 Encyclopedia Issue

The 1,242-page MODERN ENCYCLOPEDIA ISSUE for 1960 furnished subscribers with a wealth of valuable working information...through its articles, Buyer's Directory, charts, diagrams and tables. The Encyclopedia is the most inclusive, most authoritative reference work on plastics available.

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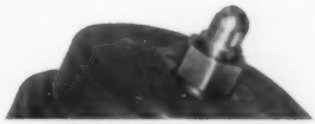

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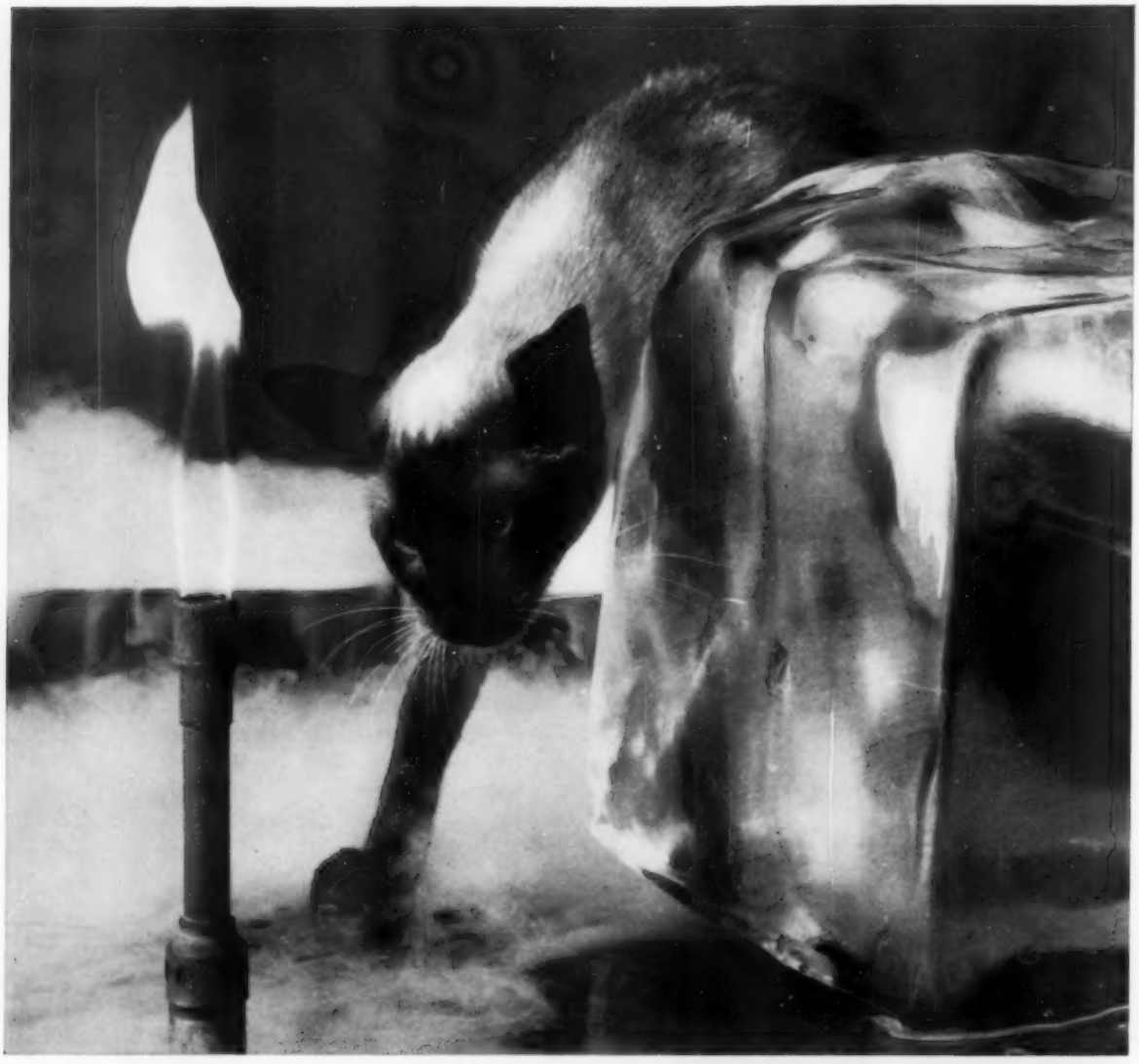

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What's the major difference between designing with metals and plastics? Time dependence of the mechanical properties of the plastics. For more details of guidelines to follow using plastics in structural design, see page 396.

Heat is a big factor in the design of molds and machinery for molding plastics. The article by W. J. B. Stokes, starting on page 417 outlines important "thermal engineering" techniques which will lower your production costs.

the editor looks at . . . . .

RF preheat time of phenolic molding materials depends on preform hardness. One simple and effective method for controlling hardness is to use a Durometer "D" tester (page 413).

1960's BEST OF ANTEC

Standardized tempering of polyethylene test sheets may pave the way towards obtaining reproducible Environmental Stress Crack test data (407).

Urethane foams with better insulation efficiencies can be made with halogenated hydrocarbon blowing agents. L.R. LeBras compares urethane foams blown with carbon dioxide and halogenated hydrocarbons (420).

Considerable improvement can be made in processes such as extrusion, injection molding and mixing, once the cause of melt fracture is understood. For fundamental data on this problem, see page 423.

Do you have mold fill-out problems? The article starting on page 429 develops information which may be valuable for design of injection molds with efficient fill-out patterns.

Dr. E. Baer *was graduated from Johns Hopkins University with a Ph.D. in Chemical Engineering in 1957. He joined the Du Pont Company as a Research Engineer with the Polychemicals Department at the Experimental Station. Since then, he has done fundamental research in the solid state behavior of plastics and the development of design principles. Before joining Du Pont, Dr. Baer did research in convective heat transfer. He is a member of the ASME and lives in Wilmington, Delaware.*

R. E. Maier *graduated from the University of Cincinnati with a Ch.E. degree in 1939. He joined the Du Pont Company as a Research Engineer at the Arlington Works. Experience with Du Pont has included supervision of both process development and fundamental research on various polymers and polymer intermediates. Current responsibility is supervision of a Plastics Engineering Research group for the Polychemicals Department.*

T. J. Linton *was graduated from Michigan State University with a B.S. in Mechanical Engineering in 1956. He joined the Du Pont Company as a Plastic Sales Technologist at the Polychemicals Sales Service Laboratory. He has done processing and product evaluation studies on injection molding resins. In the past two years he has been concerned with application design studies including plastic part design and cost estimating. He is a member of the Philadelphia Section of the SPE and lives in Centerville, Delaware.*

J. R. Knox *was graduated from Louisiana State University with a M.S. in Physical Chemistry in 1952. He joined the Du Pont Company as a Research Chemist with the Polychemicals Department at the Experimental Station. He worked on the development of continuous analyzers and mass spectrometric techniques. He spent two years with the Army doing research on radiation effects on biological systems. Since then he has done fundamental research on the effects of molecular structure on mechanical properties of polymeric materials.*

Structural Design of Plastics

E. Baer • J. R. Knox • T. J. Linton • R. E. Maier
E. I. du Pont de Nemours & Co., (Inc.)
Polychemicals Department

The object of this article is to present principles for structural design of plastics. The only data presented are those necessary to illustrate the type of information which is needed in accurate design.

The paper is in two parts. This first part, "Mechanical Properties", describes the properties frequently used by the designer of plastic articles. Under "The Stress-Strain Curve", two regions of the stress-strain curve are defined. First, the region of low strain is discussed. This region is pertinent to applications where minimum deformation of the part under load is of prime concern. The other region considered is the Yield Point, which is important when fracture or failure due to large deformation must be prevented. The section under Creep and Relaxation describes the effect of loading time on strength properties within these two regions of the stress-strain curve. Specific sections are devoted to creep under a constant load and relaxation of stress from a fixed deformation.

Part II, "Design Methods", presents the recommended methods for using the mechanical properties and concepts of Part I in plastics design. Illustrations are included to show how the equations which were originally developed for metals design can be modified. "Design Within the Modulus Accuracy Limit" (page 402) utilizes modified elastic design equations. This method is usually used when deformation of the part is of prime concern. "Yield Design", (page 404) uses design principles which originate from Plasticity Principles. In this section, the yield stress is the controlling material variable. In both, it is emphasized that the major difference between metals and plastics design is the necessity to allow for the time dependence of the mechanical properties of polymeric materials over the entire range of temperatures and environmental conditions which the part may encounter in use.

MECHANICAL PROPERTIES—Part I

The first section, "The Stress-Strain Curve", discusses the interpretation of results from elementary uniaxial tests. Various types of stress-strain curves are shown in order to illustrate typical behavior and to define such common terms as modulus, modulus accuracy limit, and yield stress. In the second section, the discussion of "Creep and Relaxation" is intended to show the importance of considering these phenomena in plastics design procedure. The application of a time-dependent modulus and yield stress is discussed.

The Stress-Strain Curve

In the tensile testing of plastics, three distinct types of stress-strain curves may be observed. These are illustrated in *Figures 1, (a, b, and c)*. Stress-strain curves, Type A and B, illustrate materials which have gradual and abrupt yielding. The Type C diagram shows a material which fails before yielding occurs. Tests conducted at room temperature using ASTM recommended strain rates showed that "Alathon"® polyethylene resin, "Delrin"® acetal resin, and conditioned "Zytel"® 101 nylon resin (2.5% moisture content), are materials which yield gradually (Type A). On the other hand, dry as-molded "Zytel" yields abruptly (Type B) and "Lucite"® acrylic resin usually fractures before yielding occurs (Type C).

The designer is usually concerned with two distinct regions of the stress-strain curve. In the first region, designated by line OA in *Figure 1*, elastic design principles may be applied. The second region around Point B, which will be referred to as the yield point, can be used when fracture or failure due to large deformation is of prime concern. In the following discussion both of these regions are considered in detail.

1. The Modulus Accuracy Limit

a. Concept

Proportional limit and elastic limit are two terms used to describe the point of termination of the linear portion of a stress-strain curve, the limit of Hooke's law. This is about Point A in *Figure 1*. However, a careful study of stress-strain curves for thermoplastics has shown that there is no linear section. Rather, there is deviation from linearity from the origin. The deviation is very slight below 0.5% strain and most published figures of elastic modulus, E_o, are the slope of a line tangent to the low strain portion of the stress-strain curve.

The secant modulus, E_s, is the slope of a line drawn from the origin to a point on the curve, and the secant modulus decreases with higher strains. Plotting E_s/E_o emphasizes that application of the initial modulus becomes less accurate with increasing strain. This is shown in *Figure 2 (a)*. This means a part in service may deflect more than calculations indicate since linearity is assumed in deriving equations for deformation.

Table 1. Corresponding Strain and Stress at 73°F at the Modulus Accuracy Limit

Material	Strain (%)	Stress (psi)
"Zytel" 101 (Conditioned)*	0.85	1400
"Delrin"	1.25	5300
"Lucite"	1.80	6900

With thermoplastics there is no "limit"; rather it is a matter of degree of deviation with increasing strain, and a concept of modulus accuracy is needed. Hence, we have chosen the term *"modulus accuracy limit"*. As an arbitrary choice, an accuracy of 15% was chosen as an allowable error in most design calculations. The corresponding strain at the modulus accuracy limit may be determined for some plastics from *Figure 2 (a)*. These strains and corresponding stresses are listed in *Table 1* above.

On a specific design problem, after the deflection is calculated, the strain or the stress should be calculated. If the "modulus accuracy limit" is not exceeded, the calculation is sufficiently accurate. Otherwise, the geometry of the part must be changed to reduce the strain (or stress), or a correction must be applied to the calculation. Each designer and each application will have specific needs for accuracy, which are related to the concept and use of a safety factor. It is through an understanding and application of a modulus accuracy limit that these specific needs are met.

b. Effect of Temperature and Loading Time

It is convenient that strain at the 15% modulus accuracy limit turns out to be essentially a material constant regardless of temperature or loading time. Strains at the 15% modulus accuracy limit were determined at several higher temperatures for "Delrin". They were found to have essentially the same value as that found at 73°F, for the 15% design accuracy as shown in *Figure 2 (b)*. Since loading time also affects stress-strain curve (longer loading times having the same effect as higher temperatures) it was deduced that the strain value at the 15% modulus accuracy limit should also be the same regardless of the loading time. In order to confirm this, the results of many creep experiments have been compared. The predicted deflections were well within 15% of the observed deflections. An example is shown in *Figure* 14.

* 2.5% Equilibrium Moisture Content at 50% Relative Humidity.

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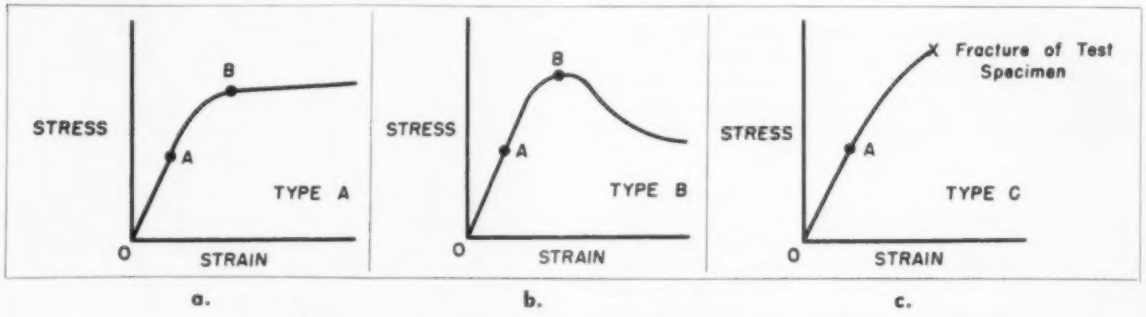


Figure 1. (a) Gradual yielding (b) Abrupt yielding (c) Fracture occurs at low strains before yielding.

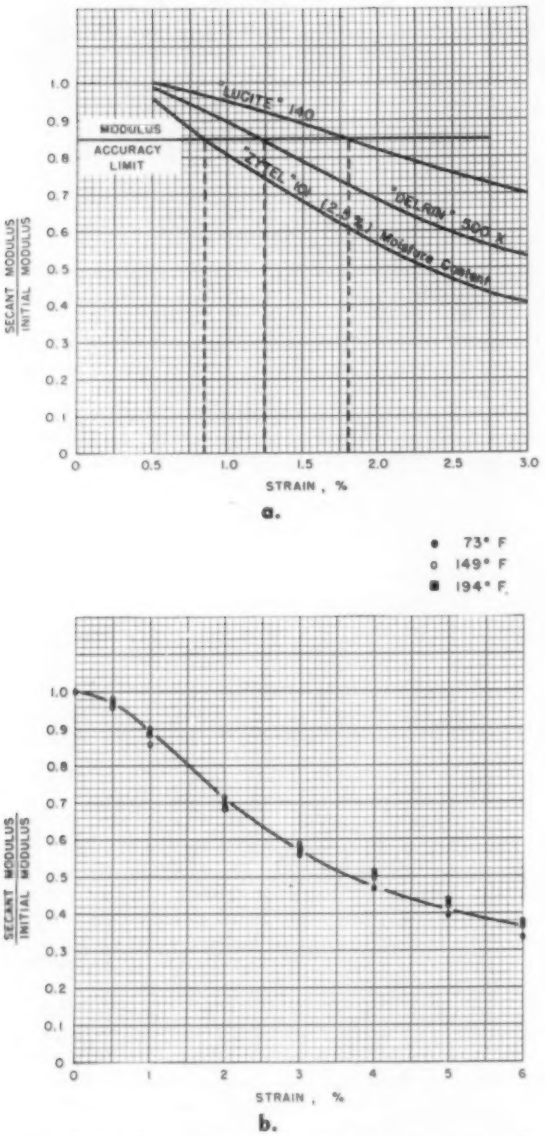


Figure 2. (a) Decrease of the ratio of secant modulus to initial modulus with increasing strain (73°F). (b) Decrease of the ratio of secant modulus to initial modulus with increasing strain "Delrin" acetal resin.

It is possible that beyond a limiting strain value, marked inaccuracies in calculations for creep deflection and stress relaxation may occur. This possibility emphasizes the importance of using the modulus accuracy limit concept as a checkpoint until or unless future data show the limit is not necessary.

c. Recovery

Many times a part is required to recover after being loaded intermittently in use. *Figure 3* presents data on "Delrin" which illustrate a particular intermittent loading sequence and show the recovery obtained. Tensile specimens of "Delrin" were initially loaded at ASTM rates to 0.7%, 1.5%, and 2.7% strain, respectively. The load was released and the strain recovery was observed. This hysteresis testing procedure was repeated five times, and each loading was to the initial stresses. The specimen which was loaded to 0.7% strain recovered completely. However, the other specimens retained some residual strain and recovery was incomplete. This is further evidence that 1.25% strain at the modulus accuracy limit for "Delrin" is valid.

2. *The Yield Point*

a. Concept

In order to define the yield point in plastics of Type A, as shown in *Figure 1* the true stress-logarithmic strain curve must first be calculated from the conventional stress-strain curve. In the conventional stress-strain curve, strain is calculated in terms of the original length of the test specimen and stress is calculated on the basis of the original cross-sectional area. Since the cross-sectional area of the test specimen changes during a tensile test, the true stress-logarithmic strain curve which is based on the instantaneous dimensional changes is more meaningful. The equations which convert conventional strain, ϵ, to logarithmic strain, $\bar{\epsilon}$, and conventional stress. S, to true stress, $\bar{S}$ are

$$\bar{S} = S\ (1 + \epsilon) \qquad (1)$$

and

$$\bar{\epsilon} = \ln\ (1 + \epsilon) \qquad (2)$$

The following examples illustrate how these equations may be used.

Example 1. A specimen is stressed 5,000 psi at a strain of 1%. What is the corresponding true stress and logarithmic strain?

$$\text{True Stress} = \bar{S} = 5000\ (1 + 0.01) = 5{,}050 \text{ psi}$$

$$\text{Logarithmic Strain} = \bar{\epsilon} = 2.303\ \text{Log}_{10}\ (1 + 0.01) = 0.0099 \text{ or } 0.99\%$$

Example 2. Based on the original dimensions, a specimen is stressed to 10,000 psi at a strain of 10%. What is the corresponding true stress and logarithmic strain?

$$\text{True Stress} = \bar{S} = 10{,}000\ (1 + 0.1) = 11{,}000 \text{ psi}$$

$$\text{Logarithmic Strain} = \bar{\epsilon} = 2.303\ \text{Log}_{10}\ (1 + 0.1) = 0.095 \text{ or } 9.5\%$$

By applying equations (1) and (2), the true stress-logarithmic strain curves are constructed from the conventional

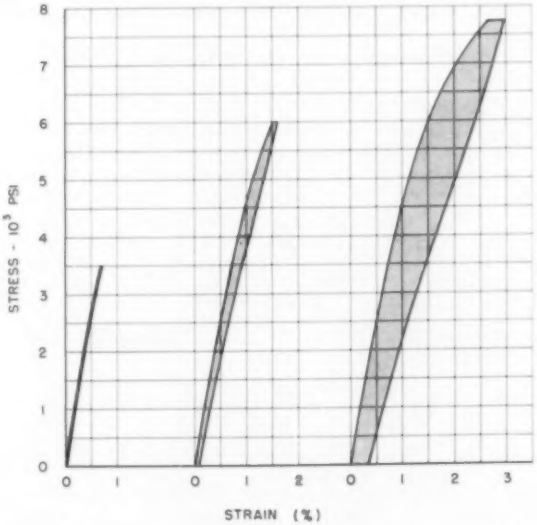


Figure 3. Strain recovery of "Delrin" (five cycle hysteresis loops at 73°F).

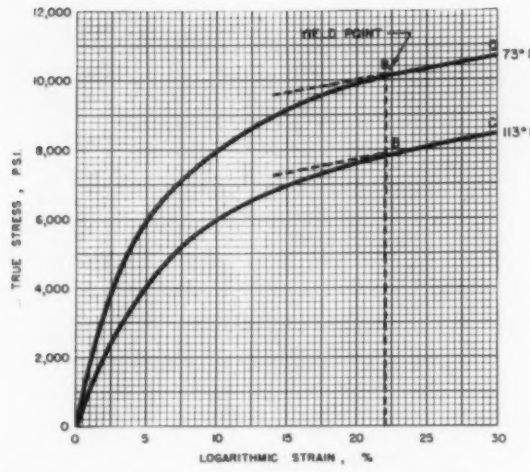


Figure 4. Tensile stress-strain curves "Zytel" 101 (2.5% moisture content).

stress-strain curve. Examples 1 and 2 show that the differences between the conventional and the true-stress logarithmic strain curves are substantial for relatively large strains and negligible for small strains within the modulus accuracy limit.

In design terminology, there are many different definitions of the yield point and therefore the danger of confusion always exists. For materials which *yield* gradually, the *yield point* is determined from the true stress-logarithmic strain curve as is shown in *Figures 4, 5, and 6*. The straight line BC is the work-hardening region of the tensile stress-strain curve, and point B, which marks the beginning of work hardening, is defined as the yield point. For materials which *yield abruptly*, the *yield point* is defined as the maximum or hump of the conventional stress-strain curve, as shown in Figure 1 (b). The stress which corresponds to the yield point is called the *yield-stress*. While this definition for materials which yield gradually differs from the ASTM definition, it is used in most texts on the Theory of Plasticity.

Figures 4, 5, and 6 are the true stress-logarithmic strain curves for "Zytel" 101 (2.5% moisture content), "Delrin" 500 X, and "Alathon" 25 measured at standard ASTM loading rates. These curves illustrate how the yield point may be determined. The yield strains are shown to be 22, 4.5, and 12.5% logarithmic strain, respectively. If a test specimen of a ductile plastic material is extended to relatively large strains, the test specimen will neck down and the cross-sectional area of the specimen becomes uncertain. The stress-strain curve beyond the yield point is of little value to the design engineer except that it adds confidence that stress concentrations can be distributed without failure by fracture.

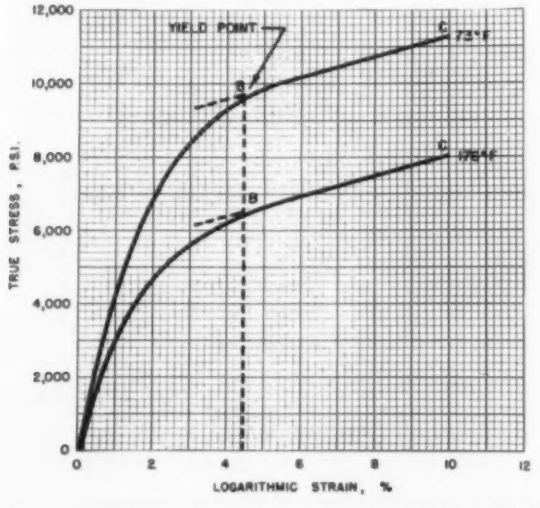


Figure 5. Tensile stress-strain curves "Delrin" 500X.

b. Effect of Temperature, Loading Time, and Environment

Tensile testing of materials at ordinary temperatures has shown that most metals are characterized by one type of stress-strain curve. This is not the case for plastics which are in general more sensitive to the temperature, the rate of testing, and the environmental conditions. "Zytel" 101 is a good illustration.

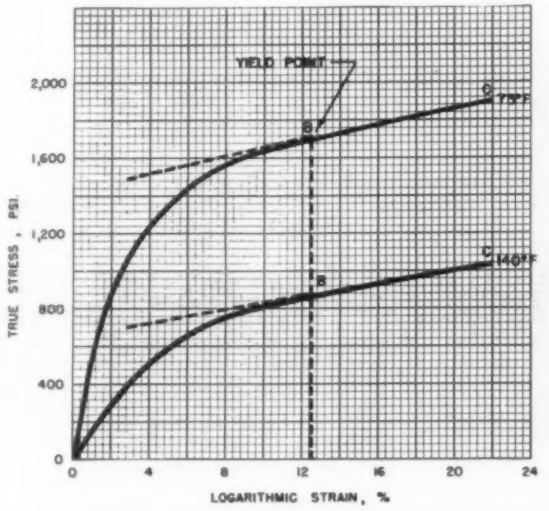


Figure 6. Tensile stress-strain curves of "Alathon" 25.

Table 2 shows how testing rate and moisture content can change the type of stress-strain diagram, thereby changing the basic design properties such as yield stress. It is very important that the designer of plastic parts know under what conditions changes in material behavior may occur and adapt the design procedure accordingly.

It is an established fact that the yield stress increases with the rate of testing. In many practical applications the load is applied at speeds which are considerably faster than the ASTM recommended testing rates and therefore the material properties which are obtained from standard tests are sometimes misleading. *Table 3* shows how the yield stress of various plastics increases with rate. High speed yield stress values are difficult to obtain experimentally and the numbers quoted represent the lowest values which have been observed on a high speed non-impact testing machine. The data are not accurate enough to show a difference between "Alathon" 10 and 14. However, in all cases, a substantial increase in yield stress with increasing rate has been observed.

Table 2. Tensile Behavior of "Zytel" 101 at 73°F

Moisture Content (%)	Strain Rate (%/sec)	Type of Stress-Strain Diagram
0.2	0.12	B
0.2	12,000	C
2.5	0.12	A
2.5	12,000	B

3. *Tension, Compression and Flexure*

In some calculations it is important for the designer to know the stress-strain curves in tension and compression. For example, in flexural design problems both types of stress-strain curves are needed because tensile and compressive stresses are present in the structure. Furthermore, various materials are considerably stronger in compression than in tension. The classical example of a nonmetallic material which illustrates this is concrete. It has been shown that for large strains the compressive strength properties of various Du Pont plastics are substantially higher than the corresponding tensile properties.

The tensile and compressive stress-strain curves for dry and moisture conditioned (2.5% moisture content) "Zytel" 101 are given in *Figure 7*. Similar curves for "Delrin" 500X and "Lucite" 140 are shown in *Figures 8 and 9*, respectively. From these curves, which were obtained at ASTM strain rates, the following conclusions can be made:

1. The tensile and compressive stress-strain curves are for all practical purposes identical at small strains. Therefore the modulus in compression is equal to the modulus in tension.
2. It follows that the flexural modulus is equal to the tensile modulus.
3. For relatively large strains, the compressive stress is higher than the corresponding tensile stress. For example, the conventional tensile stress at 10% strain for "Delrin" is 10,000 psi. The corresponding compressive stress is 17,000 psi. This means that the yield stress in compression is greater than the yield stress in tension.

Creep and Relaxation

The phenomena of creep and relaxation in plastic materials are of prime concern to the designer of plastic parts which, in use, can be only slightly deformed yet carry a load for long periods of time. Creep will take place even at low loads and low temperature and the designer must estimate its amount. For metals, analogous behavior is

Table 3. Yield Stress (psi) vs Strain Rate at 73°F Strain Rate

Material	ASTM D638-52T 0.1%/Second	ASTM D412-51T 10%/Second	12,000%/Second
"Zytel" 101 (Conditioned)*	8,600	—	13,000
"Zytel" 101 (Dry)	11,400	—	18,000
"Delrin" 500X	10,000	—	12,500
"Alathon" 10	—	1,600	3,200
"Alathon" 14	—	1,250	3,400

* 2.5% Equilibrium Moisture Content at 50% Relative Humidity.

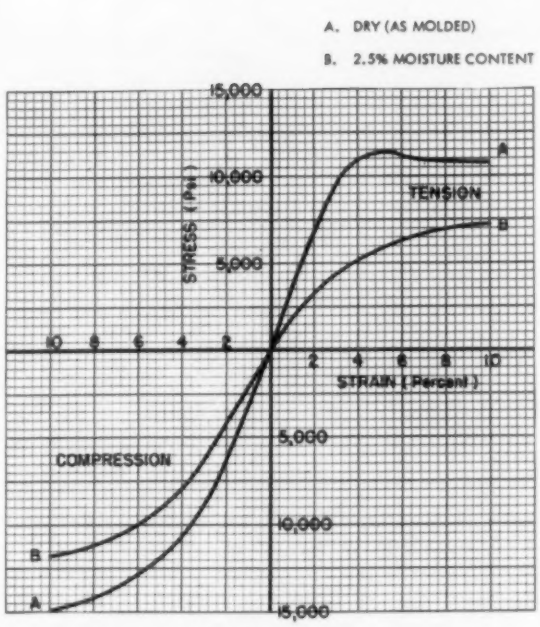


Figure 7. Conventional stress-strain curves in tension and compression of "Zytel" 101 (73°F).

usually only encountered at elevated temperatures and therefore these phenomena are of less concern.

Basic creep and relaxation behavior are measured by a simple uniaxial tension test. The data are usually given graphically. From the individual curves, the time-dependent moduli are calculated. The time-dependent creep modulus is defined by the equation

$$E_{tCreep} = \frac{\text{Stress}}{\text{Strain at Time (t)}} = \frac{F_o/A_o}{\Delta L_t/L_o} \qquad (3)$$

where

F_o = Constant Force, pounds
A_o = Original Cross-Sectional Area, inches^2
L_o = Original Length, inches

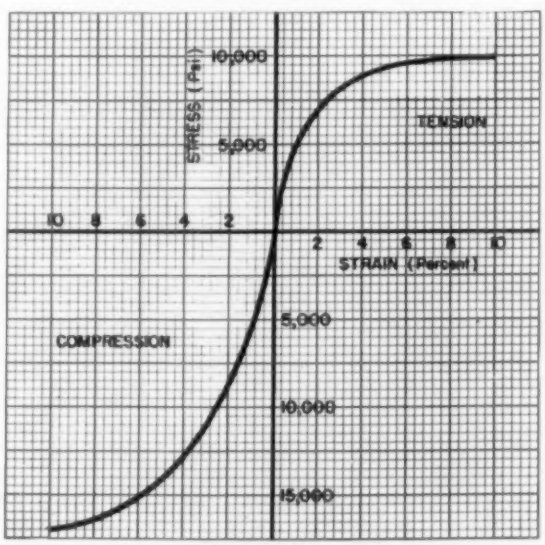


Figure 8. Conventional stress-strain curves in tension and compression of "Delrin" 500X (73°F).

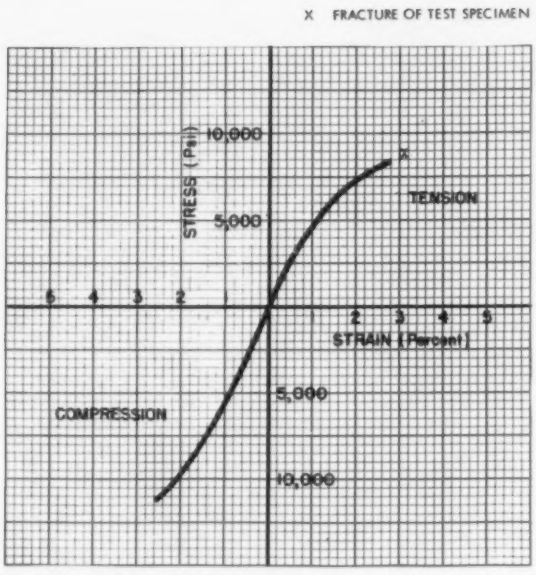


Figure 9. Stress-strain curves in tension and compression of "Lucite" 140 (73°F).

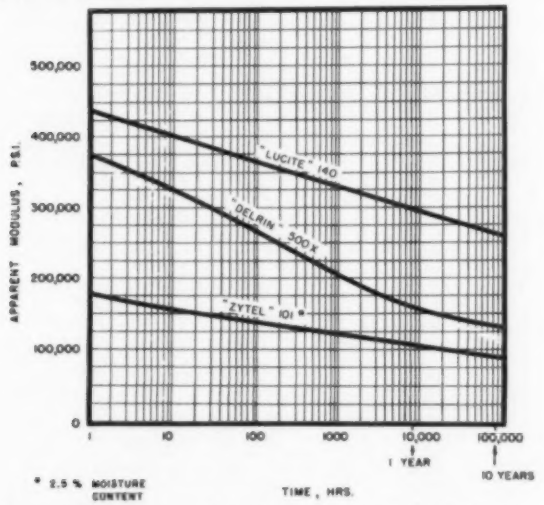


Figure 10. Apparent modulus vs. time (0.5% strain, 73°F.)

ΔL_t = Increase in Length at Time (t), inches

The time dependent relaxation modulus is similarly defined as

$$E_{t\ relax} = \frac{\text{Stress at Time (t)}}{\text{Strain}} = \frac{F_t/A_o}{\Delta L_o/L_o} \qquad (4)$$

where

A_o and L_o = Are as before
ΔL_o = Initial Deformation, inches
F_t = Force at Time (t), pounds

Tests so far have confirmed that equations (3) and (4) are applicable when the initial strain is within the modulus accuracy limit. The modulus accuracy limit is used as a checkpoint when making creep (deformation) and relaxation (force decay) calculations.

It has been shown experimentally that the creep modulus and relaxation modulus are similar in magnitude and for design purposes may be assumed to be the same. That is $E_{t\ creep} = E_{t\ relax}$. Therefore, only *one* time-dependent modulus called the *apparent modulus* is necessary. The following examples illustrate the similarity between creep and relaxation moduli.

Example 1. Determination of the apparent modulus from a creep experiment would be accomplished by placing a test bar in tension under a load of 95 pounds. The bar has an original gauge length of 5.0 inches and a cross-sectional area of 0.063 square inches. After one year, the increase in length is 0.025 inches.

$$\text{Stress (constant)} = \frac{95}{0.063} = 1{,}500 \text{ psi}$$

$$\text{Strain after one year} = \frac{0.025}{5.0} = 0.005 \text{ or } 0.5\%$$

$$E\ (1 \text{ year})_{creep} = \frac{\text{Stress}}{\text{Strain after 1 year}} = \frac{1{,}500}{0.005}$$

$$= 300{,}000 \text{ psi}$$

Example 2. Similar information would be obtained by elongating a specimen of the same dimensions to 0.5% strain, maintaining a constant strain and recording the force decay. After 1 year the force decreases to 95 lbs.

$$\text{Stress after 1 year} = \frac{95}{0.063} = 1{,}500 \text{ psi}$$

$$\text{Strain (constant)} = 0.005$$

$$E\ (1 \text{ year})_{relax} = \frac{\text{Stress after 1 year}}{\text{Strain}} = \frac{1{,}500}{0.005}$$

$$= 300{,}000 \text{ psi}$$

The use of the apparent modulus in design procedure is discussed in detail in Part II–"Design Methods". In general, the standard strength of materials design formulas are used. However, the modulus which is chosen is an apparent modulus selected on the basis of the time the part is under load.

The apparent moduli of "Lucite" 140, "Delrin" 500X, "Zytel" 101* and "Alathon" 20 are given as a function of

* 2.5% Equilibrium Moisture Content at 50% Relative Humidity.

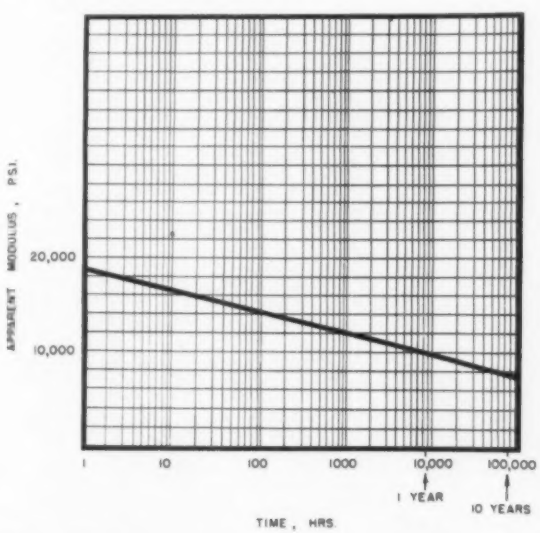


Figure 11. Apparent modulus vs. time (0.5% strain, 73°F) "Alathon" 20.

time in *Figures 10 and 11*. The curves were in all cases obtained from tensile relaxation measurements (within the modulus accuracy limit) at 0.5% strain. These graphs illustrate basic property data needed in the design of articles which in use can only be slightly deformed yet maintain a load for long periods of time.

In the design of parts in which failure due to large deformation or fracture is the major factor, the mechanical properties around the yield stress are of prime concern. In *Figures 5 and 6*, the yield strains of "Delrin" and "Alathon" 25 were shown to be about 4.5 and 12.5%, respectively. The decrease of the yield stress with time is obtained by maintaining test specimens at the yield strain and recording the stress decay with time. The tensile stress relaxation behavior of Alathon 25 from the yield strain is given in *Figure 12*. In Part II, "Design Methods", it will be shown how these properties can be used to predict the fracture of plastic pipe maintained under a constant internal pressure. Other applications of this type of property data are indicated.

DESIGN METHODS—Part II

The major difference between metals and plastics design lies in the choice of structural properties to be used in standard design theory and formulas. For metals these properties are relatively constant over wide ranges of temperature, time and other measures of environment. For plastics, structural properties are more sensitive to comparable changes in environment.

The well known stress distribution of a simple beam in flexure is the background for the recommended methods for using the concepts of Part I in plastics design. When a beam is flexed, two distinct regions of stresses are obtained which are separated by a neutral plane. On one side of the neutral plane the fibers are in tension, while on the other side the fibers are in compression. Since an idealized stress-strain curve in tension and compression is symmetrical and linear at small deformations, the stress distribution in the beam in flexure also is symmetrical about the neutral plane as is shown in *Figure 13 (a)*. This type of linear distribution, which exists only at relatively small deflections, is assumed in the derivation of the standard elastic design equations. The following section, "Design Within the Modulus Accuracy Limit", utilizes this familiar concept.

When a beam is flexed to carry maximum load, the stress distribution in the beam approaches the rectangular shape

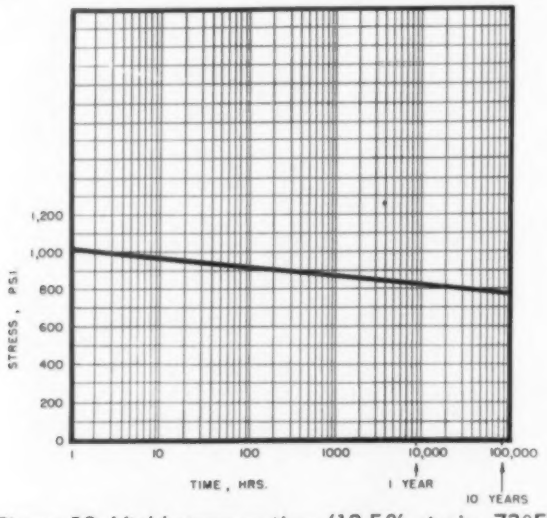


Figure 12. Yield stress vs time (12.5% strain, 73°F) "Alathon" 25.

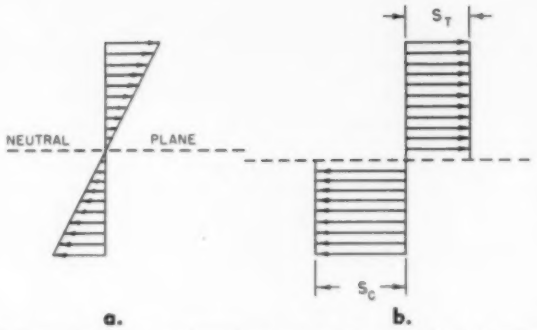


Figure 13. Stress distribution in flexure. (a.) Linear (elastic) stress distribution. (b.) Stress distribution maximum load.

shown in *Figure 13 (b)*. This can only occur if the material is ductile and does not fracture before this distribution is reached. It is important to note that the neutral plane is no longer in the center of the beam since the yield stress in compression is greater than the yield stress in tension. In the section, "Yield Design", equations derived on the basis of this type of behavior for metals are modified for plastics. The basic assumption is that a structure will fail when all the fibers have yielded. In both those sections, illustrations with simple design calculations are intended to familiarize the reader with the general procedure.

Design Within the Modulus Accuracy Limit

This section shows how the elastic design equations which were developed for metals can be applied to plastics[1]. The deflection equations are expressed in terms of two material variables, the elastic (Young's) modulus and Poisson's ratio; while the stress equations are only dependent on load and geometry [2, 3, 4]. These formulas can be converted to the appropriate time-dependent equations simply by *replacing the elastic modulus with the apparent time-dependent modulus and assuming Poisson's ratio to be a constant.*

For practical purposes, Poisson's ratio is constant with time. The other major assumption is that the stress distribution is initially linear and remains linear with time. The validity of these assumptions was checked by centrally loading a rectangular beam of "Delrin" acetal resin which was supported at the ends and observing the deflection over a period of time. *Figure 14* shows the good agreement between calculated and experimentally determined deflection-time curves. The deflection-time curve was calculated by using the equation for maximum deflection, with the modulus, E, replaced by the apparent modulus, E_t: (terms in the following equations are defined in *Table 4*)

$$Y_m = \frac{PL^3}{48\,E_tI} \qquad (5)$$

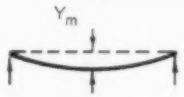
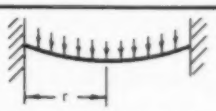
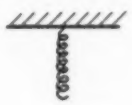
Values of the apparent modulus, which were obtained from low strain tensile relaxation measurements, were substituted in the equation and the deflection-time curve was plotted.

The equations used in calculations of this type are applicable only if the maximum stress or corresponding initial strain is within the modulus accuracy limit. The equation for calculating the maximum stress for the beam example is

$$S = \frac{3PL}{2bd^2} \qquad (6)$$

Initial strain can be calculated with Hooke's Law, that is, by dividing stress by the initial modulus:

Table 4. Typical Formulas for Designing Within the Modulus Accuracy Limit.

Geometry	Deflection Equation	Stress Equation	Nomenclature
 Centrally Loaded Beam	$Y_m = \frac{PL^3}{48\,E_t\,I}$	$S = \frac{3\,P\,L}{2\,b\,d^2}$	P = Load L = Span d = Depth b = Width I = Moment of Inertia E_t = Apparent Modulus S = Outer Fiber Stress Y_m = Maximum Deflection
 Uniform Load on Circular Plate (Edges Fixed)	$Y_m = \frac{3p\,r^4\,(1-\mu^2)}{16\,E_t\,t^3}$	$S = \frac{3p\,r^2\,(1+\mu)}{8\,t^2}$	p = Load per Unit Area t = Thickness r = Radius μ = Poisson's Ratio S = Maximum Stress
Uniform Load on Circular Plate (Edges Supported)	$Y_m = \frac{3p\,r^4\,(5-4\mu-\mu^2)}{16\,E_t\,t^3}$	$S = \frac{3p\,r^2\,(3+\mu)}{8\,t^2}$	p = Load per Unit Area t = Thickness r = Radius μ = Poisson's Ratio S = Maximum Stress
Thin Closed-End Pipe Under Internal Pressure	$Y = \frac{R}{E_t}\left(1-\frac{\mu}{2}\right)\frac{P_i\,R}{t}$	$S_h = \frac{P_i\,R}{t}$	t = Wall Thickness R = Mean Radius P_i = Internal Pressure Y = Radial Displacement S_h = Hoop Stress
 Closed-Coil Helical Spring	$Y = \frac{16\,NPD^3\,(1+\mu)}{E(t)\,d^4}$	$S_s = \frac{8\,P\,DK}{\pi\,d^3}$ $K = \frac{4C-1}{4C-4} + \frac{0.615}{C}$ $\left(C = \frac{D}{d}\right)$	Y = Deflection N = Number of Coils D = Diameter of Coils d = Diameter of Wire S_s = Maximum Shear Stress P = Load

$$\epsilon = \frac{S}{E_o} \qquad (7)$$

In this experiment, the outer fiber stress was found to be 1,500 psi by substitution into equation (6). Also, the strain was 0.41% as calculated with equation (7). Since 1,500 psi stress and 0.41% strain are less than the stress and strain at the modulus accuracy limit for "Delrin" (5,300 psi, 1.25%), good agreement between predicted and observed deflection was found.

The following examples further illustrate this method of designing within the modulus accuracy limit.

Example 1. Deformation of the base of an aerosol bottle

In the design of plastic aerosol bottles, the deformation of the base with time must be known. The slightest bulge of an initially flat bottom will cause the bottle to rock on its base. Hence, a skirt around the base is necessary if a flat bottom is intended for the container. The height of the skirt must be greater than the base deformation. To estimate the amount of deflection, the base is considered as a circular flat plate under a uniform load. In a bottle the walls add stiffness to the base. If we assume simple vertical support from the walls, we will calculate a height for the skirt that will assure that the bottle will stand erect. For this condition the equation for maximum deflection at the center of the plate is

$$Y_m = \frac{3\,pr^4\,(5-4\mu-\mu^2)}{16E_t t^3} \qquad (8)$$

and the corresponding maximum stress is

$$S_m = \frac{3\,pr^2(3+\mu)}{8\,t^2} \qquad (9)$$

To show the complete calculation, consider a bottle made of "Delrin" 500X with internal pressure of 100 psi for 1 year at room temperature.

Geometry

Radius of Plate = r = 0.75 in.
Thickness of Plate = t = 0.20 in.

Physical Constants at 73°F after 1 year *(Figure 10)*

Apparent Modulus = E_t (1 year) = 160,000 psi
Poisson's Ratio = μ = 0.38

$$Y = \frac{3 \times 100 \times 0.75^4(5 - 4 \times 0.38 - 0.38^2)}{16 \times 160{,}000 \times 0.20^3} = 0.015 \text{ inch}$$

$$S = \frac{3 \times 100 \times 0.75^2(3 + 0.38)}{8 \times 0.20^2} = 1770 \text{ psi}$$

$$\epsilon = \frac{1770}{410{,}000} = 0.0043 \text{ in./in. or } 0.4\%$$

Since the calculated maximum initial stress and strain are within the modulus accuracy limit (5300 psi, 1.25%), the calculated deformation of 15 mils is reliable. Thus, the height of the skirt which elevates the base should be at least 15 mils, so that the bottle will stand erect and firm even if slight deformation with time is encountered.

Example 2. Radial Displacement of a Pipe Under Internal Pressure

In the construction of plastic piping networks, it is sometimes important to know the radial displacement of the wall of a pipe which is under internal pressure for a period of time. The radial displacement and the mean hoop stress of a thin closed-end pipe under internal pressure may be calculated using the following equations:

$$\text{Radial Displacement} = Y = \frac{R}{E_t}\left(1 - \frac{\mu}{2}\right)\frac{P_i R}{t} \quad (10)$$

$$\text{Mean Hoop Stress} = S_h = \frac{P_i R}{t} \quad (11)$$

Consider as an example a pipe made of "Zytel" 101 nylon resin conditioned to 2.5% moisture content. The pipe contains compressed air at 73°F and 50% relative humidity and is under a pressure of 150 psi for 5 years.

Geometry

Mean Radius of Pipe = R = 0.50 in.
Wall Thickness = t = 0.10 in.

Physical Constants at 73°F after 5 years

Apparent Modulus = E_t (5 years) = 95,000 psi
Poisson's Ratio = 0.40

$$Y = \frac{0.50}{9.5 \times 10^4}\left[(1 - 0.20)\frac{150 \times 0.50}{0.10}\right] = 0.0031 \text{ inch}$$

$$S_h = \frac{150 \times 0.50}{0.10} = 750 \text{ psi}$$

$$\epsilon = \frac{S_h}{E_o} = \frac{750}{175{,}000} = 0.0043 \text{ in./in. or } 0.43\%$$

The calculation shows that the radius of the pipe would increase by 3.1 mils in five years. The radial displacement is a realistic estimate since both the initial stress and strain did not exceed the modulus accuracy limit for "Zytel" 101 (1400 psi, 0.85%).

The two preceding examples apply only to calculating deformation. In biaxial stress systems, such as pipe and aerosol bottles, fracture due to excessive stress is another factor which must be considered in the over-all design. Examples that illustrate the calculation of burst stress are are given in the following section under "Yield Design",

Example 3. Closed-Coil Helical Spring Under A Tensile Load

At present, there are only a few spring applications for plastics. This calculation shows that plastic materials are quite suitable for use in springs and can be designed to carry substantial loads for short periods of time with complete recovery. The deflection of a closed-coil helical spring under short term load is

$$\text{Deflection} = Y = \frac{16\,NPD^3(1 + \mu_s)}{E_o\,d^4} \quad (12)$$

and the maximum shear stress on the outer fibers is

$$\text{Maximum Shear Stress} = S_s = \frac{8\,P\,D\,K}{d^3} \quad (13)$$

where

$$K = \frac{4C - 1}{4C - 4} + \frac{0.615}{C} \text{ and } C = \frac{D}{d}$$

For the purposes of this calculation, consider a closed-coil helical spring made of "Lucite" 140 acrylic resin at 73°F. The spring has 10 coils and a load of 5 lbs. is applied intermittently for no more than 1 minute.The spring must recover completely.

Geometry

Diameter of Coil = D = 1.50 ins.
Diameter of Circular Section = d = 0.25 in.

Physical Constants at 73°F

Initial Modulus = E_o = 450,000 psi
Poisson's Ratio = μ = 0.40

$$Y = \frac{16 \times 10 \times 5 \times 1.50^3(1 + 0.40)}{4.5 \times 10^5 \times 0.25^4} = 2.16 \text{ inches}$$

$$S_s = \frac{8 \times 5 \times 1.50 \times K}{3.14 \times 0.25^3} = 1.22 \times 10^3 K$$

Since

$$C = \frac{1.50}{0.25} = 6$$

$$K = \frac{24 - 1}{24 - 4} + \frac{0.615}{6} = 1.25$$

Therefore,

$$S_s = 1.22 \times 10^3 \times 1.25 = 1{,}500 \text{ psi}$$

From the tensile stress-strain curve (*Figure 9*), the stress at the modulus accuracy limit in tension for "Lucite" 140 at 73°F is 6,900 psi. The stress at the modulus accuracy limit in shear (torsion) can be estimated from the stress at the modulus accuracy limit in tension from the relation

$$S_{shear} = \frac{S_{tension}}{2(1 + \mu)} \quad (14)$$

Substitution into equation (14) shows that the shear stress at the modulus accuracy limit is 2,500 psi or greater than the maximum shear stress in the preceding example. Hence, it is concluded that a spring with this geometry can be loaded intermittently (5 lbs.) without permanent deformation.

Yield Design

The previous section considered the deformation of structures under load. In ultimate load determinations, the designer is primarily concerned with the stress required for failure. In both cases, accurate design can be accomplished only if the effect of time and temperature on the mechanical properties is known.

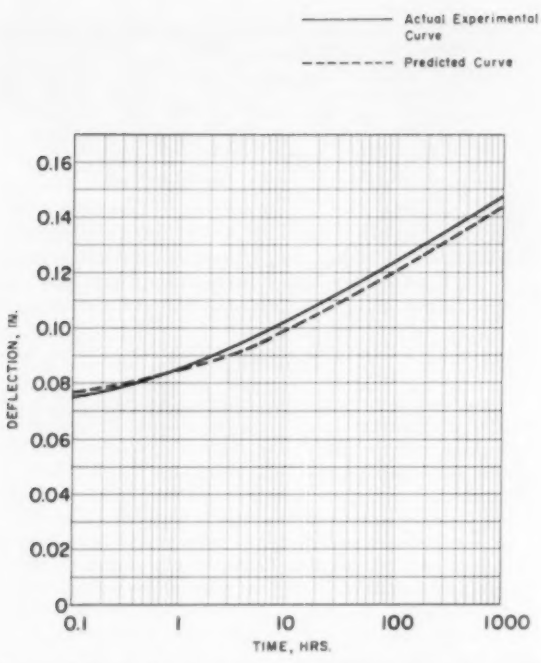


Figure 14. Deflection of a centrally loaded beam with time ("Delrin" 500X, 73°F., end supports).

Standard formulas used in limit design are found in various textbooks dealing with the "Theory of Plasticity" [5, 6, 7]. The equations can be used in designing structures made of plastics if the yield stress at time of failure is known. Experimental evidence justifying this procedure has been obtained in a number of cases. The simplest example is the determination of the maximum load that can be sustained by a centrally loaded beam with supported ends. Failure occurs when all the fibers in tension reach the yield stress in tension and all the fibers in compression reach the yield stress in compression (*Figure 13*). The following equation is used to calculate the maximum load:

$$P_{max} = K \frac{bh^2}{L} \qquad (15)$$

where

$$K = \frac{2S_T S_c}{S_T + S_c}$$

where, b, h, L are the width, depth and span respectively, S_T is the yield stress in tension and S_c is the yield stress in compression. The validity of this equation has been shown by measuring the maximum load-carrying capacity of beams of "Delrin" 500X at 73°F. According to equation (15), a plot of P_{max} versus the moment of inertia $\frac{bh^2}{L}$ should give a straight line on a linear plot. *Figure 15* gives the results of these beam deflection tests compared with a calculated data line. The slope of this line, K, is obtained by substitution into equation (15). From tensile and compressive data given in *Figure 8*, S_T and S_c are found to be 10,000 psi and 17,000 psi, respectively. A good correlation was obtained.

At the present time, the greatest use of this method is made in predicting the failure of pressure vessels such as pipe and aerosol bottles. In order to obtain the solutions to these types of multiaxial stress problems, the von Mises-Hencky yield condition is applied to plastics.

$$(S_1 - S_2)^2 + (S_2 - S_3)^2 + (S_3 - S_1)^2 = 2S_T^2(t) \qquad (16)$$

S_1, S_2, and S_3 are the three principle stresses and S_T (t) is the yield stress in tension at the time of failure. The application of this condition in predicting the failure of pipe is shown below.

The three principle stresses in a pipe are the hoop stress, S_1 the longitudinal stress, S_2, and the radial stress, S_3. For a closed-end pipe with a *thin* wall $S_1 = 2S_2 >> S_3$, and substitution into equation (16) gives

$$S_1 = S_{hoop} = \frac{2}{\sqrt{3}} S_T\,(t) \qquad (17)$$

where

$$S_{hoop} = \frac{P_i r}{t}$$

P_i is the internal pressure, r is the internal radius and t is the thickness. Equation (17) shows that the hoop stress at time of failure is equal to the yield stress in tension at time of failure multiplied by a constant. This relation shows that pipe failure can be predicted if the change in tensile yield stress under continuous load is known. For example, in *Figure 16* the solid line is the change in the tensile yield stress with time for "Alathon" 25 at 73°F. This curve was obtained from tensile relaxation measurements. According to theory in a homogeneous pipe the yield stress in tension at time of failure equals hoop stress times $\frac{\sqrt{3}}{2}$. Actual pipe burst data verify this. The following examples are intended to further illustrate this technique.

Example 4. Pressure Capacity of a Closed-End Tube with Thick Walls

The equation which should be used for the allowable pressure of thick wall vessels is

$$P_i = \frac{2}{\sqrt{3}} S_T\,(t) \quad \ln \frac{R}{r} \qquad (18)$$

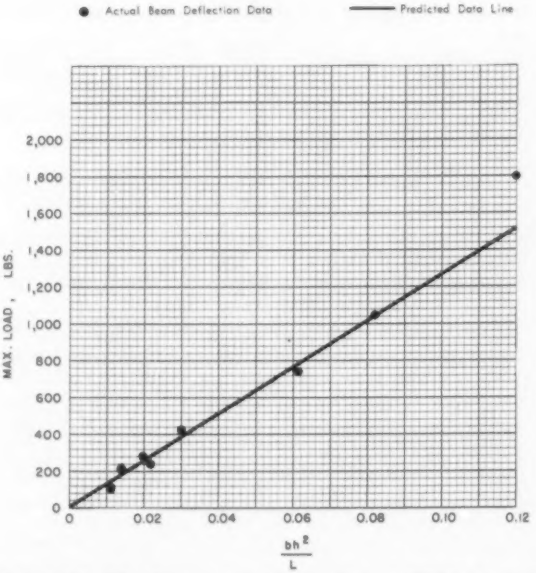


Figure 15. Maximum load capacity at 73°F of centrally loaded beams of "Delrin" 500X.

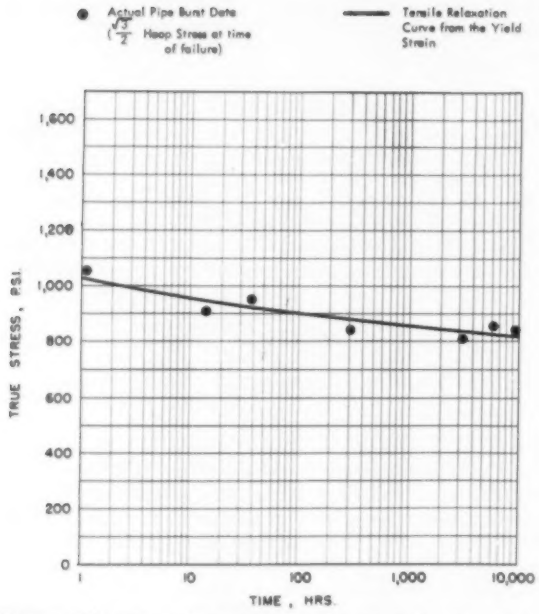


Figure 16. Prediction of pipe burst behavior "Alathon" 25 at 73°F.

where r and R are the internal and external radius, and S_T (t) is the yield stress in tension at time of failure. The internal pressure which a tube of "Alathon" 25 polyethylene resin will endure after 1 year is determined below:

Geometry

Internal Radius = a = 0.5 inch

External Radius = b = 1.0 inch

Physical Constants at 73°F after 1 year *(Figure 12)*

Yield Stress in Tension = S_T (1 year) = 820 psi

$$P_i = \frac{2 \times 820 \times 2.303}{1.732} \log_{10} \frac{1.0}{0.5} = 660 \text{ psi}$$

Therefore, a tube of "Alathon" 25 having this particular geometry will endure an internal pressure of 660 psi for 1 year.

Substantial errors can be made if the equation which applies only to thin wall pipe is used in calculations involving thick walls. This is shown by substitution in equation (17).

$$P_i = \frac{2 \times 820 \times (1.0 - 0.5)}{1.732 \times 0.5} = 950 \text{ psi}$$

That is, the calculated pressure using the thin wall equation is nearly 50% higher than the actual pressure.

Example 5. Failure of a Tube with Hoop Stress and Longitudinal Stress Equal

The von Mises-Hencky yield condition can be applied to many design problems, and the closed end tube under internal pressure is just one case. This example shows how the yield condition can be modified for a thin wall tube placed under pressure and tension. Assume that the tube is pulled longitudinally so that this stress is doubled. That is, $S_1 = S_2 >> S_3$. Substitution into equation (16) gives

$$S_1 = S_{hoop} = S_T (t) \qquad (19)$$

A comparison of equations (17) and (19) shows that the constant factor, $2/\sqrt{3}$, has decreased to unity. This means that doubling the longitudinal stress has decreased the pressure capacity of the pipe by only 15%.

Example 6. Prediction of Yield Stress in Torsion from the Yield Stress in Tension

The two principal stresses in pure torsion are equal and opposite, $S_1 = -S_2$. The stress in the other direction is zero, $S_3 = 0$. Substitution into the yield condition gives

$$S_1 = S_s (t) = \frac{S_T (t)}{\sqrt{3}} \qquad (20)$$

Delrin 500X, e.g., has a yield stress in tension of 10,000 psi at 73°F when tested at a strain rate of 10%/min. Applying equation (20), the torsional yield stress at the same strain rate is predicted to be about 5,800 psi. Actual experiments have shown the torsional yield stress to be 5,600 psi.

In conclusion, it must be emphasized again, that the "Theory of Plasticity" can be applied only if yielding has taken place before failure. As a rule, ductile materials may be treated in this manner. The equations which have been developed are not applicable to brittle materials since they do not yield. Materials of this type usually fracture due to stress concentrations caused by flaws in the structure. At or below ASTM recommended strain rates, "Delrin", "Zytel" and "Alathon" may in general be considered as ductile materials. However, "Lucite" does not yield before fracture and therefore the application of limit design methods is not recommended.

The examples given in Part II of this paper illustrate the principles of either limited deformation (Designing Within the Modulus Accuracy Limit) or maximum stress at failure (Yield Design). In certain cases, usually biaxial stress systems such as pipe and other pressure vessels, both deformation and the maximum stress at which the part will fail should be calculated.

This paper discusses the engineering aspects of structural design with plastics. Other important requirements such as cost, appearance, electrical, chemical, weathering, etc, which must be considered in the over-all design of the component part have been purposely omitted from this paper.

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Effects of Thermal History on Some Properties of Polyethylene

John B. Howard and William M. Martin

Bell Telephone Laboratories, Inc.

This article shows how theoretical studies can lead to information of immense practical value to fabricators. It offers promise, for the first time, of a reasonable level of reproducibility in laboratory testing for those properties of polyethylene sensitive to difference in crystalline content or texture. Fabricators now have a practical method of establishing, beforehand, outside limits in a given polyethylene of the properties in which they are interested.

The critical importance of the prior thermal history of the specimen in tests for crystallinity-sensitive properties of polyethylene has been underscored by recent efforts to standardize a method of test for environmental stress-cracking in ASTM (1-3) and has been given prominence in other recent work. (4-7) The conditions usually employed for molding or extruding polyethylene result in an admixture of its more stable crystalline and less stable amorphous forms, with the precise ratio of the two, as well as the character and size of the crystallites present sharply dependent upon the specific conditions and equipment involved. Pieces molded from the same lot of material in different presses, or even in the same press with seemingly trivial differences in procedure, often vary substantially in the amount and nature of their crystallinity, or in other words in their crystalline texture (8), and this variation is reflected in the results of sensitive physical tests.

The crystalline-amorphous balance normally achieved is, moreover, a metastable one. With the passage of time further crystallization takes place accompanied by modifications of crystalline texture. These changes occur the more rapidly the higher the temperature up to approximately the melting point of the lowest melting fractions present. Above this temperature the rate of cooling from the elevated

Table I. General Properties of Materials Studied[1]

Property	ASTM Test Method	Sample A	Sample B	Sample C[2]
Density (g/ml)	D 1505-57T	0.9175	0.9207	0.9188
Melt Index	D 1238-57T	1.6	0.25	0.42
Tensile Strength (Kg/cm^2)	D 412-51T[3]	124 (1770 psi)	177 (2520 psi)	150 (2130 psi)
Stress at Yield (Kg/cm^2)	D 412-51T[3]	103 (1460 psi)	120 (1700 psi)	100 (1420 psi)
Elongation (%)	D 412-51T[3]	660	720	730
T_B (°C)	D 746-57T	−99	−112	−91
Environmental Stress-cracking (F_{50}-hr)	D 1693-59T[4]	1.3	1070	>2000

[1] As normally determined on molded sheet conditioned per Procedure A of ASTM Designation: D 618-58.
[2] Ocean cable insulating compound containing 5% by weight Butyl Rubber 217.
[3] Straining rate: 50 cm/min.
[4] Apparatus and procedure of ASTM Designation: D 1693-59T used, but F_{50} determined.

temperature may be the controlling factor. (7)

This behavior renders duplication of test results for crystallinity-sensitive properties difficult under the best of circumstances, especially in interlaboratory testing, and makes it all but impossible otherwise. Of course, not all solid state properties of polyethylene are affected equally. The most susceptible are those which are most strongly crystallinity-dependent. Density, environmental stress-crack resistance, and impact brittleness are typical examples.

Attempts to circumvent or counter this situation have been made in a number of ways. The direct approach of attempting to so spell out the details of molding equipment and procedure that universally reproducible moldings can be made appears impractical (2), and post-molding tempering of the test sheets or specimens seems more feasible. Boiling in water, one of the first procedures suggested, has been shown to be only partially effective. (2) Preconditioning at 70°C is now practiced in some places and may have merit for certain polyethylenes. Pelagatti and Baretta (7) have demonstrated beneficial effects from preconditioning at 50°C for at least the polyethylenes they studied. These procedures all have in common the fact that the crystalline texture and crystalline content finally achieved are strongly influenced, if not largely determined by the original molding cycle because the status established at that time is not destroyed by complete remelting. Heat treatment below the melting point may develop latent or embryonic crystalline features otherwise not prominent in the molded piece, but the over-all pattern and texture remain basically that established during transition through the critical crystallization temperature range during the cooling portion of the original molding cycle.

Many workers, including the present authors, have carefully remelted polyethylene test sheets in an inert atmosphere and cooled them very slowly over excessively long periods in an effort to destroy the effects of previous thermal history. Prior to the simple but ingenious proposal of Birks and Rudin, (9) the remelting process usually also destroyed the test sheet as such, leaving a mass of polymer suitable only for determination of bulk properties like density. The innovation introduced by Birks and Rudin consists of the use of thin aluminum parting sheets which have the happy faculty of adhering tightly enough to sheets of polyethylene pressed out in a "picture frame"-type mold that the sandwich so formed can be transferred to an oven, heated above the melting range of the polymer involved, and then cooled under controlled conditions to furnish a usable test sheet whose prior thermal history has been effectively obliterated and replaced by a reproducible standard pattern.

In the work reported here, the efficiency of the Birks and Rudin technique, which will be referred to as the CIL procedure, in eradicating the consequences of prior thermal history is examined using the environmental stress-crack (ESC) test of ASTM Designation: D 1693-59T as a sensitive criterion of effectiveness. The effects on environmental cracking, density, and low-temperature brittleness of a broader range of conditions, including the extremes of slow- and shock-cooling suggested by these authors, is also ex-

Table 2. Improvement in Reproducibility of ESC Test After Melt Tempering
ASTM Type I Class A Grade 4 Polyethylene[1] (Sample B)

Cooling Time During Molding Cycle	Environmental Stress-crack Resistance[2] (F_{50}-hr)			
	Tested "as molded"		Remelted and Cooled 7C/hr	
(min)	Spec. 1-10	Spec. 11-20	Spec. 1-10	Spec. 11-20
1	320	140	2.3	2.1
3	595	907	2.4	2.0
5	499	835	2.6	2.8
7½	67	78	2.2	1.8
10	67	67	3.5	2.5
Average and 95% confidence limits	358 ± 237 hr		2.4 ± 0.4 hr	
Standard Deviation	314 hr		0.5 hr	
Coefficient of Variation	87.8%		20.8%	

[1] ASTM Designation: D 1248-59T
[2] Using apparatus and procedure of ASTM Designation: D 1693-59T

amined. Lastly, a comparison is made in the low-temperature brittleness test of ASTM Designation: D 746-57T of the standard specimen, the notched version suggested by Birks and Rudin, (9) and the smaller ABSNAC specimen described by Bestelink and Turner, (5) using a range of tempered states.

EXPERIMENTAL

Materials and Molding

Three polyethylenes were used in this study: an ASTM Type I Class A Grade 3 polymer of melt index 1.6 (10), a Type I Class A Grade 4 polymer of melt index 0.25, and a 5% butyl rubber ocean cable insulating compound having a melt index of 0.42. The butyl rubber compound was based on a Type IA4 polymer similar to the second sample but of slightly higher melt index. These materials are roughly characterized in *Table 1*. No attempt was made to extend the study to ASTM Types II or III polymers.

Each of these materials was worked briefly on a 15x33 cm two-roll laboratory mill at 130°C to homogenize it and to disrupt previously existing crystal structure. 15x18 cm sheets of two thicknesses, 0.32 cm for environmental stress-crack testing and 0.19 cm for other tests, were molded from the homogenized stock of each material using approximately the procedure described by Birks and Rudin.

A weighed quantity of the millmassed material was placed in the opening of a brass "picture frame" mold chase between solvent-cleaned sheets of 0.018 cm dead-soft aluminum foil backed by smooth 0.6 cm aluminum plates. This unit was placed in a small press whose plattens had been preheated to 150-160 C and 25,000 kg ram pressure applied for 5 minutes. Pressure was maintained during cooling to 32°C, which process consumed approximately 5 minutes except in the case of the sheets for the stress-crack reproducibility study, for which a range of cooling times was employed (cf. *Table 2*). When the mold was taken from the press, the backing plates were removed but care was taken not to disturb the aluminum foil or the mold chase.

In addition, two sheets 25x25x0.32 cm and two more 0.19 cm thick were molded from each homogenized stock in a compression mold in a large press using the 25-minute molding cycle which has been standard in our laboratory. This cycle involves 5 minutes heating, 3 minutes at 160°C, then cooling at a uniform slow rate down to 32 C in approximately 17 minutes.

Tempering and Sample Preparation

A portion of each 25x25 cm sheet was reserved in the "as molded" state for control purposes, and for the ESC reproducibility study one 15x18 cm sheet molded at each of the cooling rates was tested without further conditioning. Other portions of each 25x25 cm sheet were tempered for 30 minutes in boiling water or for 7 days in an air oven at 70°C. Because these sheets did not enjoy the restraint of a "picture frame" and the aluminum foil, they could not be subjected to the CIL tempering procedure.

The smaller sheets prepared for this purpose were placed, with their aluminum foil parting sheets still undisturbed, on a smooth metal plate in an oven preheated to 140°C. They were maintained at this temperature for 45 minutes to ensure complete remelting of the polymer. For shock-cooling, the aluminum foil "sandwiches" were removed one at a time from the oven and quickly transferred to a wire basket suspended in a tank of running tap water at approximately 18°C. They remained in this tank for not less than 15 minutes. For the slow-cooled condition the aluminum foil units were left in the oven following the 45-minute remelting period and the temperature dropped at a uniform rate of approximately 7°C per hour by means of a motor-driven variable transformer in the power supply. This was normally accomplished overnight and so did not consume valuable laboratory time. The sheets were finally removed from the oven at approximately room temperature.

After either the shock- or the slow-cooling, the aluminum foil was stripped off and the sheets removed from the molding frames. The entire procedure was essentially as reported by Birks and Rudin, (9) differing only in details considered to be minor for purposes of this discussion.

After tempering as described above, specimens for environmental stress-crack testing were die-cut from the 0.32 cm sheets. Specimens for the low-temperature brittleness tests were cut from the 0.19 cm sheet, D 746 specimens using a die and ABSNAC specimens by means of the automatic device described by Bestelink and Turner. (5) Addition of a notch as suggested by Birks and Rudin (9) to some of the D 746 specimens was accomplished using a special jig to limit the depth of the notch to 0.040 cm and to position it so that it would be just outside the jaws of the holder when the specimens were mounted for test. Small cubes for density determination were hand-cut with a razor blade.

Test Procedures

a. Density: Determined in accordance with ASTM Designation: D 1505-57T (density gradient column) immediately after tempering. Values reported are averages of at least three specimens.

b. Environmental Stress-cracking: The apparatus and procedure of ASTM Designation: D 1693-59T were used except that F_{50} values (time required for 50% of the specimens to fail) were determined and that Hostapal HL (12) was used in place of Igepal CO-630 (13) as the cracking agent in certain tests as shown in Table III. Ten specimens were tested except in the reproducibility study where 20 specimens from each of ten sheets were involved.

c. Low-temperature Brittleness: Comparison was made of three types of specimen as follows using the apparatus and procedure described in ASTM Designation: D 746-57T:

1. the standard 3.0x0.64x0.19 cm specimen
2. the same type of specimen bearing in one edge the 0.040 cm notch described above (9)
3. the 2.0x0.25x0.19 cm ABSNAC specimen. (5)

The latter required a special holder, and their small size offered the advantage of testing ten specimens at one time instead of the usual five.

THE TEST RESULTS

Reproducibility Study

The first of the three objectives of the present work was, as stated earlier, to verify in the laboratory the improved reproducibility of test data for a typical crystallinity-sensitive property of polyethylene afforded by the CIL tempering procedure. For this purpose one resin, one standard condition, and one test were deemed adequate in view of the success already reported in a more extensive study. (9) Selection of the Type IA4 polymer, the slow-cooled tempering, and the environmental stress-crack test made it possible to obtain definite and unambiguous results in a reasonable length of time using a test known to be ultra-sensitive to variations in the thermal history of the specimen. Our results shown in *Table 2*, solidly support the recommendations of Birks and Rudin.

The range of cooling times used in molding these test sheets was intended to simulate to some extent the results of variations in procedure and equipment existing from laboratory to laboratory. Insofar as the test data for these sheets in the "as molded" state bear more than a passing resemblance to some of the ASTM round robin results, (2)

this objective can be considered achieved. As the data show, precision under these circumstances was extremely poor, with the standard deviation almost as large as the F_{50} value itself.

However, when duplicate sheets molded in the identical ways were subjected before testing to the standardized slow-cool tempering procedure, two important differences were observed:

1. The F_{50} value was found to decrease sharply, ostensibly because the treatment had enhanced those features of crystallinity which facilitate environmental stress-crack failure.
2. More important, the precision of the test was found to have been improved very substantially.

This improvement does not appear to be ascribable merely to the fact that failures were obtained in a shorter time since the coefficient of variation, which is unaffected by the size of the numbers involved, dropped from 87.8% for the "as molded" state to 20.8% after tempering. While this hardly represents perfection, it is a very substantial gain. It means that there is now available a means for examining some of the remaining variables in the ESC test without obscuration as heretofore by uncontrollable molding variables.

Effects of Tempering on Selected Properties

Having confirmed the beneficial effects of proper tempering on one ultra-sensitive property, we can have reasonable confidence that other crystallinity-dependent properties of these materials will benefit similarly and go on to consider more broadly the consequences of some differing kinds of post-molding tempering on several such properties.

a. On Density:

Reproducible determination of density is very important since this property furnishes one of the primary bases for classification of ethylene polymers. It is so used in the present ASTM Standard for these materials, D 1248-59T. In addition, changes in density can serve as a convenient yardstick by which to gauge other changes.

The data in *Table 3* and *Figure 1* indicate that tempering which involves elevated temperatures below the melting point of the polymer tends to increase density to some extent, but far less than does slow-cooling from the melt. Boiling in water for 30 minutes raises the density of the molded sheet less than does exposure to 70°C for 7 days, which in turn has less effect than the CIL slow-cooling. The densities of test sheets molded in the normal manner are found to lie, as might be anticipated, between those for fast- and slow-cooled sheets of the same material, but with a tendency to be somewhat nearer the latter. Addition of butyl rubber appears to minimize the increase in density on tempering.

The fast- and slow-cooled states represent the extremes of density as well as of the other properties involved in this study. It is not to be inferred, however, that they necessarily represent the ultimate attainable under the extremes of quenching or of annealing in the critical crystallization range. It is in fact to be expected that a broader range of densities than found here could be achieved with but little effort. In earlier work with samples of the same general type, differentials twice as large as those reported here were noted between highly quenched and annealed states. (14)

The important thing to bear in mind is that the densities of test sheets of these materials as ordinarily molded could fall anywhere in the range between the fast- and the slow-cooled, or in extreme cases even outside this range. Their crystallinity-dependent properties would vary accordingly. If the molding procedure used in one laboratory produces test sheets near one end of this range, that in another sheets near the other end, there must inevitably be disparity between test results for any susceptible property in the two. *Small wonder, then, that better agreement has not been found in round robin testing for such properties as environmental stress-crack resistance!*

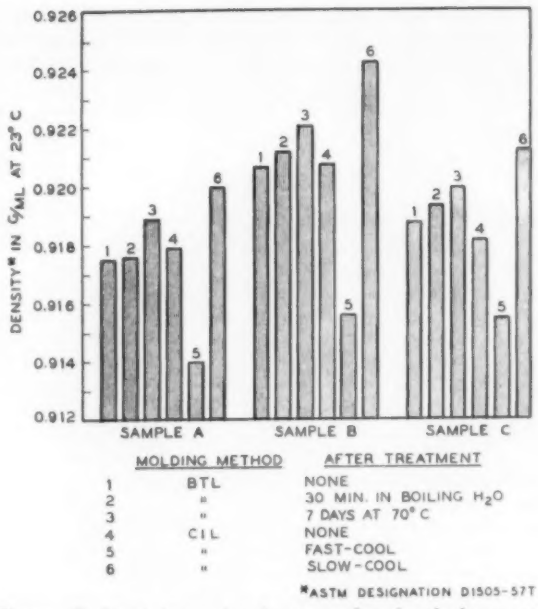

Figure 1. Variations in density of polyethylene test sheets with different thermal histories.

Why does not a process like boiling in water suffice to correct for differences in molding procedure? There are several reasons for this. One of the more germane to the present discussion arises from the fact that there appears to be an equilibrium density level characteristic of each polyethylene at a given temperature (6). Specimens whose den-

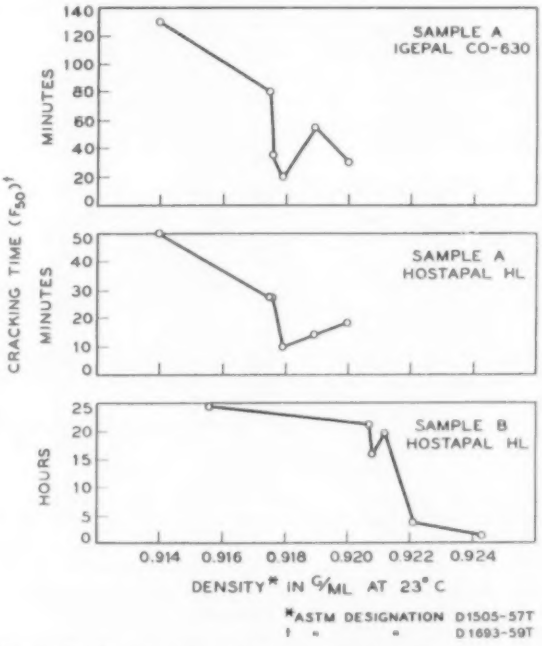

Figure 2. Environmental stress-crack resistance vs thermally induced density changes in two polyethylene compounds.

Table 3. Effects of Tempering on Selected Properties of Polyethylene

Molding Method	Conditioning	Density[1] (g/ml)	Environmental Stress-cracking[2] Igepal CO-630	Environmental Stress-cracking[2] Hostapal HL	Low-temperature Brittleness[3] Stnd. Spec.	Low-temperature Brittleness[3] (T_B-°C) Notched[4]	Low-temperature Brittleness[3] (T_B-°C) ABSNAC[5]
			Sample A (Type IA3-M.I. 1.6)				
			(F_{50}-min)	(F_{50}-min)			
BTL[6]	None	0.9175	80	28	−99	−19	−26
BTL	30′ boiling water	0.9176	37	28	−58	−20	−23
BTL	7 days at 70°C	0.9189	55	14	−82	−18	−19
CIL[4]	None	0.9179	21	10	−79	−33	−15
CIL	Slow-cool	0.9200	29	19	−52	−11	− 8
CIL	Fast-cool	0.9140	130	50	−99	−34	−42
			Sample B (Type IA4-M.I. 0.25)				
			(F_{50}-hr)	(F_{50}-hr)			
BTL	None	0.9207	1070	21	−112	−49	−61
BTL	30′ boiling water	0.9212	>2000	19½	−103	−58	−58
BTL	7 days at 70°C	0.9221	45	3½	−111	−49	−54
CIL	None	0.9208	>2000	16	− 98	−60	−43
CIL	Slow-cool	0.9243	8	1¼	−104	−27	−25
CIL	Fast-cool	0.9156	>2000	24½	−116	−67	−69
			Sample C (Butyl Compound-M.I. 0.42)				
			(F_{50}-hr)	(F_{50}-hr)			
BTL	None	0.9188	>2000	>2000	−91	−32	−42
BTL	30′ boiling water	0.9194	>2000	>2000	−64	−28	−35
BTL	7 days at 70°C	0.9200	>2000	32½	−85	−29	−31
CIL	None	0.9182	>2000	>2000	−73	−39	−32
CIL	Slow-cool	0.9213	7¾	2¼	−66	−16	−23
CIL	Fast-cool	0.9155	>2000	>2000	−91	−45	−45

[1] ASTM Designation: D 1505-57T
[2] Apparatus and procedure of ASTM Designation: D 1693-59T used.
[3] Apparatus and procedure of ASTM Designation: D 746-57T used.
[4] As described by Birks and Rudin (ref. 8).
[5] As described by Bestelink and Turner (ref. 5).
[6] As described in text.

sity is below this equilibrium value will come up to it, but those whose mode of preparation has produced greater crystallinity cannot be brought down without remelting. Thus while the densities of the untreated and fast-cooled sheets of Sample A can, for example, be brought up to a common density by boiling, that of the slow-cooled sheet cannot be brought down by the same process. What is more important, the crystalline texture of the three will remain different. This characteristic is largely established during the original molding process and is alterable only by remelting.

b. On Environmental Stress-crack Resistance:

The stress-crack data of *Table 3* support several conclusions. It is clear, in the first place, that the previous history of the test sheet has a large effect on the apparent environmental stress-crack resistance of a given polyethylene. Heat treatment below the melting point and slow cooling from the melt obviously tend to augment any predisposition toward cracking, while fast cooling has the opposite effect. Unfortunately, the apparent improvement in crack resistance in the latter case is short-lived as has been shown earlier. (6)

Although environmental crack-resistance appears in a general way to decrease as density increases, no reliable relationship between these properties is evident in these data (cf. *Figure 2*). Because of the large number of indeterminate values involved, only about half of the data admit to graphic analysis and these show no consistent pattern. This is in agreement with the earlier finding that continued exposure to an elevated temperature leads eventually to an apparently asymptotic value of density while stress-crack resistance continues to decrease. (6) Both the earlier and the present observations are interpreted as indicating that under heat treatment changes can occur in the crystalline texture of polyethylenes which have little or no effect on density but which strongly affect stress-crack resistance. The present data support the thesis that environmental stress-crack resistance can be influenced by both the amount and the nature of the crystallinity present. Both are the product of the thermal history of the test piece.

It is also apparent from the data in *Table 3* that suitable choices of tempering and test reagent should make it possible to shorten substantially the time required for achieving positive results in the environmental stress-crack test with even the more resistant polymers. Data are shown for only two reagents, but there is available a wide spectrum with different activities, ranging from distilled water through the alcohols and mild soaps to the strong detergents and the combinations of these with water and/or polar solvents which constitute the most rigorous cracking agents. Using only the two standardized tempering procedures proposed by Birks and Rudin, a single test temperature, and a range of four or five standardized reagents, it should be possible to obtain meaningful ESC data on most polyethylenes within 24 to 48 hours. In addition to providing attractive economies of testing time, this approach also minimizes the unwanted effect of creep relaxation which can color the results of tests running for long periods. (15, 16)

c. On Low-temperature Brittleness:

The data in *Table 3* show a very marked effect of tempering on the low temperature impact brittleness of polyethylene. Contrary to the case for environmental stress-cracking,

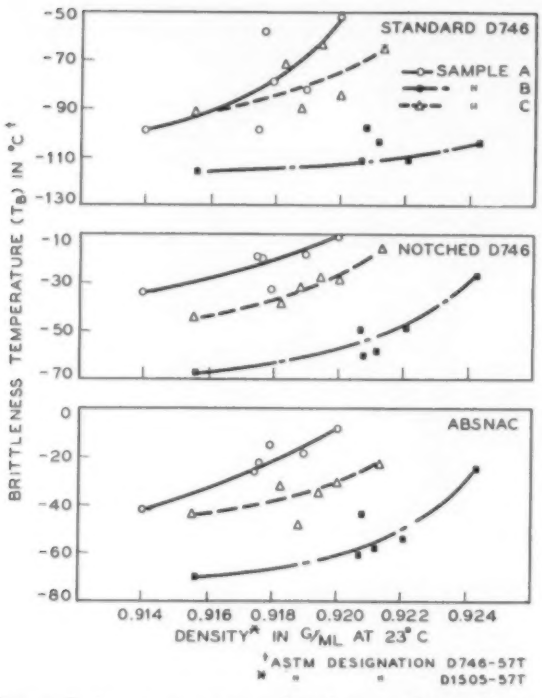

Figure 3. Low-temperature brittless vs thermally induced density changes in three polyethylene compounds.

however, this behavior appears definitely related to the density of the specimen. The curves of *Figure 3* demonstrate this. Quite evidently a standardized thermal history for the test specimen is as essential to precise results in this test as in the ESC test.

The effect found for a notch in the edge of the standard test specimen is very pronounced but in light of the published work of Bestelink and Turner (5) cannot be called unexpected. Its proponents at Canadian Industries, Ltd. suggest it as endowing the standard D 746 specimen with many of the advantages of the smaller ABSNAC specimen, which is also notched. Both result in a narrower spread of data and a substantially higher 50% break point (T_B).

This higher brittleness temperature is of interest for two reasons: first, it approximates more closely the impact failure temperature for these materials in highly strained condition, as for example a pipe clamped onto a metal fitting before cooling; and second, it simplifies the mechanics of running the test appreciably because temperatures need not be taken as low.

The ABSNAC specimen has the additional advantages of being more conservative of sample and of permitting the testing of ten specimens simultaneously in the standard apparatus. The former can be a very important consideration where only a limited amount of sample is available, as in the case of materials which have been weathered for very long periods. The latter obviously makes for economy of testing time.

Practical Significance of Tempering Procedure

Questions will arise as to the relationship between the properties found for test sheets tempered from the melt in the manner proposed and those of practical moldings or extrusions of the same material. It is fairly obvious that in most practical applications a state of crystallinity somewhere between those of the fast- and slow-cooled tempered sheets will be achieved. Will not the level of any crystallinity-dependent property then also be intermediate to those of the tempered sheets? Very definitely. What then is the practical value of such a procedure?

Simply and concisely this: it offers promise, for the first time, of a reasonable level of reproducibility in interlaboratory testing for those properties of polyethylene sensitive to differences in crystalline content or texture. The utter futility of attempting to standardize and reproduce molding conditions from laboratory to laboratory has been thoroughly demonstrated in ASTM stress-cracking round robins. Standardized tempering from the melt should at least make possible reproducible specification and raw material control testing, which is no small accomplishment. From raw materials tests on properly tempered sheets, the fabricator can establish beforehand the outside limits in a given polyethylene of the property or properties in which he is interested, but for determination of how that polyethylene will perform with respect to crystallinity-sensitive properties in a given molded or extruded article, there remains no recourse but to test that article, or a section of it, fabricated exactly as in production. In no other way can the precise crystalline state of the polymer be reproduced with certainty; in no other way can meaningful tests for crystallinity-sensitive properties be made. Data from studies like the present one demonstrate how completely variations in molding procedure can control such properties.

ACKNOWLEDGMENT

The authors gratefully acknowledge the assistance of A. M. Birks and A. Rudin of Canadian Industries, Ltd. in providing advance copies of their published work, and of V. T. Wallder of Bell Telephone Laboratories, Inc. in offering helpful advice.

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Edward W. Vaill *graduated from Colgate University in 1932. That same year he joined the Union Carbide Plastics Company where he was active in sales promotion in the New York area. In 1937 he was assigned to the New England territory where he was engaged in technical sales of both thermosetting and thermoplastic materials. In 1957 he was appointed as Technical Service Engineer, with headquarters in New York, in the phenolic molding material field. He is a member of the Society of the Plastics Industry, the Plastics Pioneers Association, and the Society of Plastics Engineers. In the latter organization he is co-chairman of the Compression Molding Group of P.A.G. and a member of the Editorial Advisory Board for the SPE Journal. In 1950 he was President of the Western New England Section of the SPE and last year was moderator for the Thermosetting Session of the 15th SPE ANTEC.*

For the Molder

A Simple and Accurate Method for Controlling Preform Hardness

E. W. Vaill
Union Carbide Plastics Company
Division of Union Carbide Corporation

Durometer "D" scale tester helps maintain high production standards for molded phenolic parts.

The preform hardness of phenolic molding materials has a major effect on their radio frequency preheat characteristics. Measurement of the preform hardness with a Durometer "D" scale tester is a simple and accurate method of controlling preform hardness once the optimum hardness rating has been established for a given material and preform size. Controlled preform hardness and uniform, maximum preform temperature are essential to present day high production requirements of phenolic molded parts produced by the compression, plunger or closed mold methods.

At the present time, there is no generally accepted or widely used method of accurately measuring preform hardness. This article will correlate in chart form the Durometer hardness of preforms of phenolic molding materials with radio frequency preheat time and temperature for the following types of materials: general-purpose, woodflour- filled; medium-impact, cotton-flock filled; and heat-resistant, mineral-filled phenolic compounds.

Once an optimum preform hardness range, usually within plus or minus 5 points, has been established for a particular material in a given preform size, it is essential to maintain this hardness range for the entire production run of material and molded parts if maximum production rates with a minimum of rejected molded parts are to be accomplished.

Figure 1. Durometer hardness tester in manual operation.

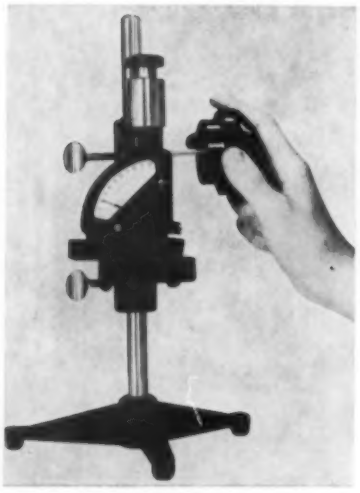

Figure 2. Tester mounted in a stand next to preform machines.

Preforms having uniform hardness or density will electronically preheat to a more uniform temperature, cycle after cycle. This reduces to a minimum the molded parts which are blistered due to undercure from too cool preforms or porous molded parts due to precure of the material from preforms which are too hot.

Figure 1 demonstrates the use of the Durometer hardness tester in a manual operation. The tester can be carried in the pocket of the Molding Department Supervisor or Inspection Engineer and may be used for check testing Durometer hardness at the molding press.

Operation

Figure 2 shows the Durometer hardness tester mounted in a stand which can be placed adjacent to the preform machines. The mounted tester can be used by the preform press operator in checking the hardness of preforms throughout his production of a given size preform of a given material.

The fundamental operation of this type of hardness tester consists of penetrating the specimen with a needle-like indentor. The geometry of the penetrating point of the indentor and the spring pressure behind it is determined by the type of material being tested. The Type D Shore Tester used in this investigation has a spring pressure of 10 pounds with an indentor having a sharp 30 degree included angle point. The length of the indentor is 0.10″. The quadrant style dial is rated from 0 to 100 and indicates inversely the distance of penetration of the indentor into the preform. For example, if the dial reading is 15 the indentor penetrates 0.085″, indicating that the preform is extremely soft. If the dial indicator reads 100, the indentor has not penetrated the specimen at all, indicating extreme hardness of the specimen.

The average general-purpose preform, which is sufficiently compressed so that the granules just stick together, will have a reading of approximately 15. A preform which is especially hard will have an indicator reading of approximately 90. The normal hardness range of general-purpose phenolic materials, which are generally used for both compression and plunger molding, runs between 50 and 70. At least 2 readings on each bottom and top of the preform should be made to obtain an average.

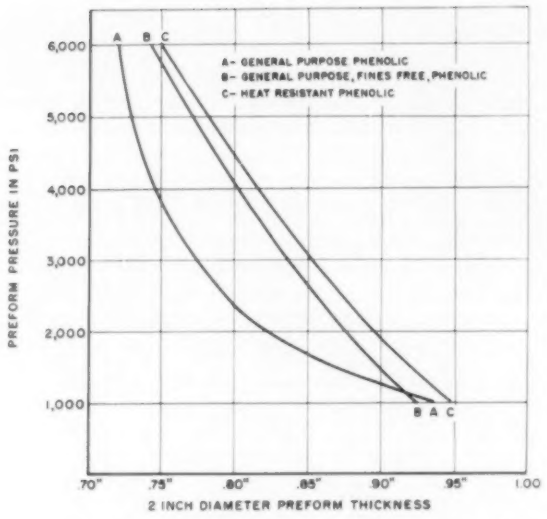

Figure 3. Preform pressure of 4000 p.s.i. produces preforms with optimum hardness.

The actual hardness of the preform as measured by the Durometer tester is not as important as the hardness limits in which a production lot of preforms is maintained. For a given weight of preforms, a hard preform will be considerably thinner than a soft one; therefore the radio frequency preheat top electrode must be lowered to maintain a constant air gap for the thinner preform. The fact that the bottom and top electrodes are then closer together for the harder preform will result in its heating more rapidly than a wider air gap for the thicker, softer preforms of the same weight.

In order to maintain uniform radio frequency preheat temperatures of multiple preforms in a preheater, irrespective of whether they are placed on the electrode on edge

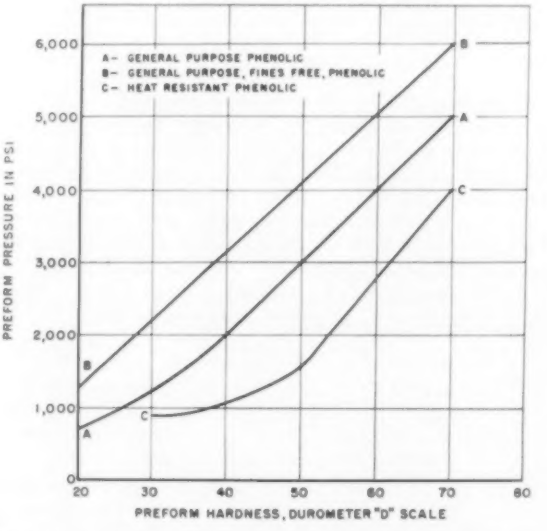

Figure 4. Heat-resistant materials (line C) have higher Durometer hardness at lower pressures because of lower bulk factor and greater density of the material.

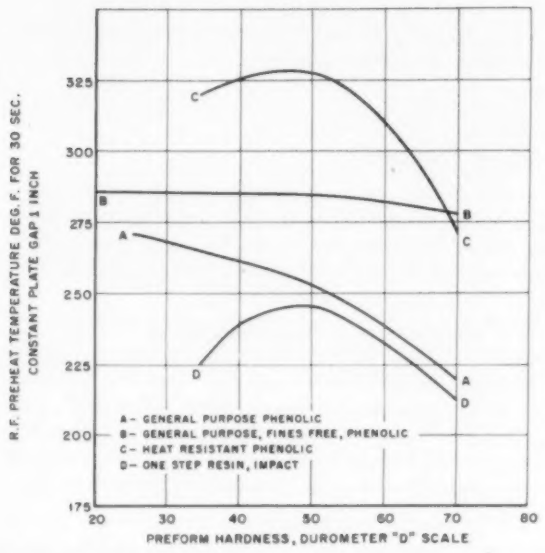

Figure 5. As general-purpose material preform becomes harder, it also becomes thinner and drop-off in temperature to which it may be preheated in a given time is substantial.

or stacked flat, it is essential that they should be approximately the same hardness in order that they may each absorb the same degree of electrical energy.

Preform Pressure— A Critical Factor

Figure 3 shows the relationship between preform pressure in pounds per square inch and preform thickness of a representative general-purpose phenolic material, a general-purpose, fines-free phenolic material, and a heat-resistant phenolic material having a specific gravity of 1.60. It has been determined by preheating and molding tests that a preform pressure of approximately 4000 psi produces preforms with optimum hardness. *Figure 3* shows the pronounced reduction in thickness of a constant weight preform with increase in pressure.

Figure 4 shows the relationship between preform pressure in pounds per square inch and Durometer hardness. It will be noted that for general-purpose materials, the Durometer hardness at 4000 psi is 60 and the fines-free material has a Durometer hardness of 50. Heat-resistant materials, as shown by line C, have a higher Durometer hardness at lower pressures because of the lower bulk factor and greater density of the material.

Figure 5 shows the relationship between R.F. preheat temperature in degrees F. for 30 seconds as affected by preform hardness. A constant plate gap of 1" is used.

It is interesting to note that as a general-purpose material preform becomes harder, it also becomes thinner and the drop-off in the temperature to which it may be preheated in a given time is substantial. This is due mainly to the greater air gap between top of preform and upper electrode or plate.

Line B demonstrates that the temperature for a preform produced of a fines-free, fast-curing, general-purpose type material is not as sensitive to variations in preform hardness or preheat air gap clearance as the other materials evaluated for this data. On the other hand, heat-resistant phenolic preforms, line C, are extremely susceptible to changes in their R.F. preheating characteristics according to hardness and thickness. The same applies to line D, a one-step, cotton-flock filled, impact material which was preheated to a lower temperature since thinner preforms were used; this was due to the higher bulk factor of the material which required greater compressing in the preform operation.

If multiple stacks of preforms are heated simultaneously, variations in Durometer hardness from one preform to another will result in considerable variations in the temperature of the preforms. Depending on the electrode gap and the capacity of the R.F. preheater, some preforms

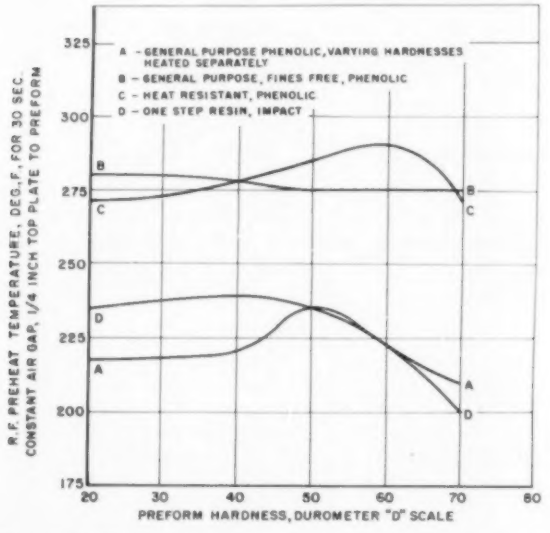

Figure 6. Temperature is lower in a given time as preform is made harder.

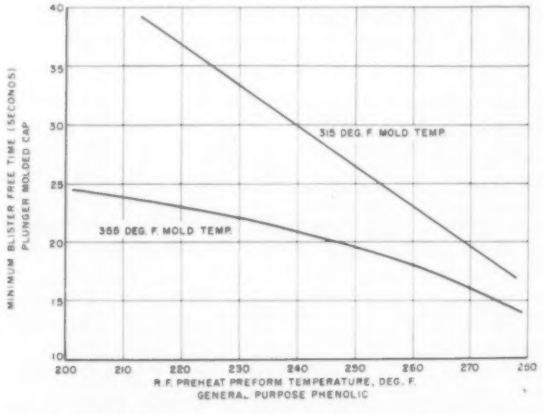

Figure 7. Unless multiple charge of preforms are at a uniform temperature, blistered and undercured parts will result during the plunger molding cycle unless the cure time is lengthened.

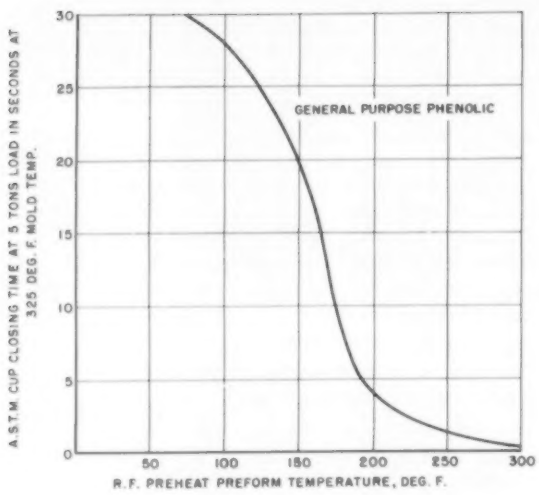

Figure 8. Softness of the heated preforms determines the closing time of the mold and is important for maximum productivity and complete filling of mold.

may not heat sufficiently to have immediate mobility under molding pressure, while other preforms in the same stack are too hot and will precure causing retarded flow or porous molded parts.

It is accepted practice in the industry to either change the air gap between electrodes or change the preheat time to overcome non-uniform preheating. If all preforms are in the same hardness range, such changes in air gap or preheat time can accomplish the desired results; but if preforms are not of the same density or hardness, such changes will result in high molding rejects due to variations in the temperature of the preforms.

Figure 6 demonstrates the effect of Durometer hardness on the temperature of the preforms heated separately with a constant air gap of ¼" between the top of the preform and the upper electrode. It will be noted that the temperature is lower in a given time as the preform is made harder. This again demonstrates the necessity for maintaining uniform hardness range of preforms for uniform preheating temperatures.

Blister Formation Affected by Preform Temperature

In order to fully understand the effect of preform temperatures on molding characteristics, we show in *Figure 7* how the minimum blister-free cure time in seconds of a plunger molded cap will vary according to the temperature of the preforms. This is calculated with mold temperatures 315°F. and 355°F. From this chart it can readily be seen that unless the multiple charge of preforms are at a uniform temperature, blistered and undercured parts will result during the plunger molding cycle unless the cure time is lengthened. This same phenomena will be present if multiple preforms are heated for charging a multiple cavity compression mold. Unless the preforms are at approximately the same temperatures, and assuming that the part is being molded on a fast cycle, the cooler preforms will result in rejects because of blistering or undercuring.

Uniformity of Preform Temperature

Figure 8 demonstrates the effect of preform temperatures on the flow characteristics of the material. The softness of the heated preforms determines the closing time of the mold and is very important for maximum productivity and complete fill-out of the molded part.

This uniformity of preform temperatures is also of vital importance where multiple preforms are charged into the well or pot of a transfer or plunger mold. It is interesting to note the substantial variation in mold closing time according to the temperature of the preforms. This again demonstrates the importance of the uniform R.F. preheat temperatures which can readily be controlled by preform hardness.

On the basis of this investigation and preform hardness tests made on materials being used in several molding plants, we recommend that the Durometer hardness of preforms on the D scale be maintained within the following range, within limits of plus or minus 5 points.

	Preform Hardness Range
General-Purpose Phenolic Molding Materials	50-70
Mineral-Filled, Heat-Resistant Phenolics	60-70
Improved-Impact, Cotton-Flock Filled Materials	50-60

Hardness testers of the Shore type range in price from $65 to $85 and the testing stands in which they can be mounted may be purchased for around $150.

Considering the simplicity of the test and the low investment for equipment, we believe the data we have presented will be of interest to the molder in maintaining high quality production with a minimum of molded part rejects for blisters and/or porous sections.

Acknowledgment

The author wishes to thank F. W. Ducca of Union Carbide Plastics Company's Development Technical Service Department for his assistance in the preparation of this paper.

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Thermal Consideration in Mold Design

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Approaches to present-day problems in the design of molds and presses, where heat control is a factor

Heat is, and always has been, a factor in the design of molds and machinery for the molding of plastics. Today it has, in many instances become a serious problem of control. Heat override in injection cylinders can degrade the plastic in them. Improper heat distribution in molds can impair the quality of the molded pieces both as to strength and dimensional stability. Speed of cycling in injection machines has been pretty much dependent on the ability to get heat in and out of the plastic material quickly.

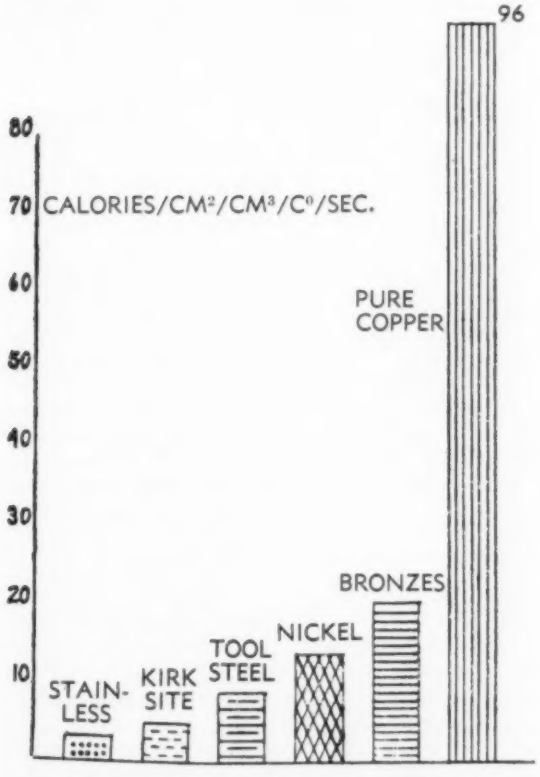

Figure 1. Heat Conductance of Metals

Basically the heat problems break down into three categories: (1) Getting the heat to where we need it. (2) Getting the heat away from where we don't want it. And (3) Keeping the heat in the proper place. Problems one and two are problems of heat conductance, while problem three is one of insulation.

First consideration in tackling these problems is to find out what tools there are to work with, and the characteristics of the materials being used. As metal is about the only material practical for use in high pressure molding equipment, considerations are being confined to this material. The heat conductance, or heat insulating, properties of metals suitable for use in such equipment is shown in *Figure 1.*

The two extremes in this chart are stainless steel and pure copper, stainless being our best insulator, and pure copper our best conductor. Many people have used stainless steel in molds, but few have used copper. The type of copper referred to in this article is not the commonly known soft copper, but hard copper such as can be produced by special electroplating techniques. This copper can be made to have a hardness of 200 to 300 Brinell. This is sufficiently hard so that it can be used satisfactorily, if judiciously ap-

plied, in and around the cavity area of injection molds, and in many other spots around molds for both thermoplastics and thermosets.

Copper has about twenty-five times the heat conductance rate of stainless steel; common tool steel conducts heat almost three times as fast as stainless, and beryllium copper is better than twice as good as tool steel.

Selecting the Materials

In compression molds for thermosets there have been two chronic problems. One is the problem of heating outside corner cavities in multiple cavity molds, while the other is the problem of getting heat down into the ends of long force plugs. The great heat conductance rate of copper can aid in both of these problems. Copper plated on the top of the steam plate, or on the bottom of the cavity plate, can even out the heat distribution over the whole mold.

On long force plugs a core of copper, it need not be hard, can carry many times more heat to the end of the core than can the steel it replaces. A one inch diameter copper plug in the middle of a two inch steel core will conduct three times as much heat to the tip of the core as will the steel around it, ten times as much heat as the steel it replaces.

In injection molding, copper finds a similar use in the heating of extension nozzles. These can be coated with a plated layer of copper for almost their full length to the tip of the nozzle. This can eliminate the need for a heater in a tight spot. Properly applied it can bring more heat to the nozzle than a heater, and it can be a controlled heat. Caution: The copper must be kept away from contact with the mold as it will conduct too much heat into the mold itself. Chrome plate over the copper sheath will insulate the nozzle against radiant heat loss.

The use of copper in the main heating cylinder of injection machines has not been fully considered. Here's one way it might be used: A large copper forging might be shrunk over a steel heating cylinder of minimum wall thickness. Into this copper forging could be drilled holes which would permit the use of cylindrical heating cartridges which would be not only much cheaper in cost of replacement, but could be easily replaced without any disassembly. Because of its very considerable rate of heat conductance the thickness of the copper needs little consideration. Thermostats placed in such a copper sheath will record much more reliably than they now do in steel cylinders. The large mass of copper proposed will also act as a considerable reservoir of heat. This, and its conductance, will mean less overriding in the heat control.

In this same area, the use of copper in the heating cylinder torpedo should be considered. A hard copper torpedo protected by plating of nickel or chrome, or both, would increase greatly the heat put into the plastic.

Stainless steel would be the material to consider for insulating the loading area of the heating cylinder, and for use in cylinder supports, where they are used.

Heat Removal—a Problem

Every calorie of heat put into the plastic in the heating cylinder has to be removed from it in the mold. It is relatively easy to calculate how much heat must be removed, and what it takes to do it. Generally, it can be figured that half of the heat will go out through the cavity, and half through the force plug, or the opposing cavity half. As the cup, or box, shaped piece is the most common configuration, the reader's attention is directed to this general shape.

Getting heat out of the cavity is generally the easier thing to do. It is easy to build in water cooling channels that have

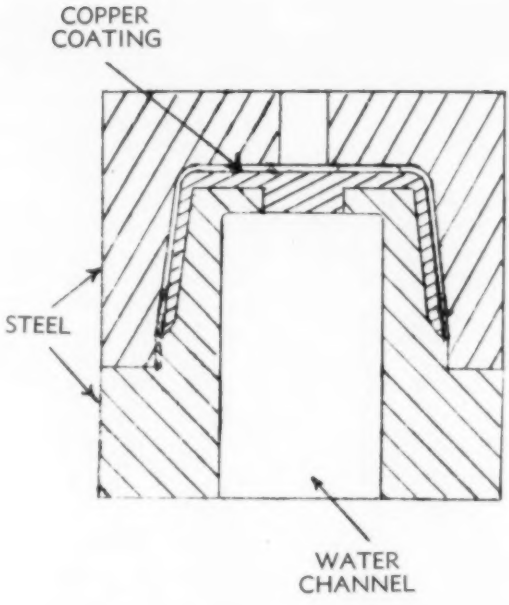

Figure 2. Schematic Section of Molds

a considerable wall area and they can be brought quite close to the cavity walls. The problem with cavities is generally one of holding the temperature constant over the surface of the cavity. With some of the polyolefins this can be a critical problem. The cooking pan solution of copper plating the outside of the steel cavity can generally eliminate the need for elaborate cooling channels and set ups for zone cooling. Copper backed electroformed cavities, and to an extent beryllium copper cavities, solve the problem automatically, though these are not always practical or desirable.

With force plugs the problem is far more severe. The area of the possible water channel is far less than in the case of the cavity. The surface area of the force plug will be about that of the cavity, but the water channel area will be but a fraction of that available to the cavity.

There are real problems here. There are a great many molds running in this country today whose production rate is severely curtailed because of the necessity of waiting for the force plug to get rid of its heat. Three things can be done to help the escape of this heat. The most effective is to coat the outside of the force plug with electroplated hard copper. Take a simple shape of force plug and see how effective this will be. The metric system is used because its units are of a more appropriate size for the purpose at hand.

One ounce of plastified plastic holds about 2400 calories that have to be removed. A force plug 3 cm. diam. and 5 cm. high will lose about 35 calories per second through its base for a temperature differential of 50°C. If we machine .3 cm. off the OD of the plug and replace this with plated copper the heat rate into the mold base will be increased to 90 cal/sec. If the thickness of the copper is increased to .6 cm. the heat conductance will be increased to 135 cal/sec. A solid copper force will carry away 315 cal/sec.

If a water hole is put in this force 1 cm. in diameter and 4 cm. deep this would carry off 20 cal/sec. with a 50°C temperature differential. All the above are necessarily very rough computations and must be considered as proportional rather than actual. Because of molding conditions computa-

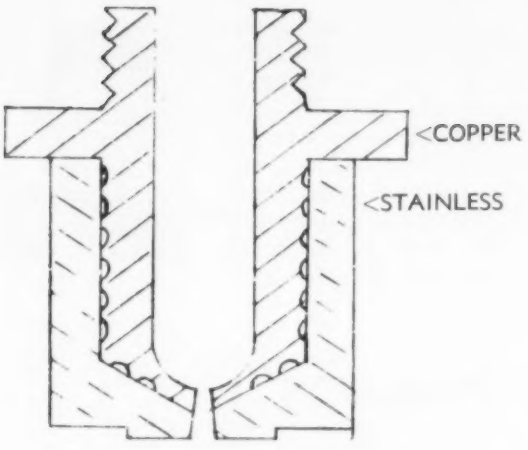

Figure 3. "Freezeproof" Sprue Bushing

tions of actual heat transfer rates get very complicated. However the proportions between the various methods of heat withdrawal can be easily estimated.

While only a few of the tricks mentioned here have actually been put into practice, the coating of a force plug with copper is one that has actually been done. (See *Figure 2*) It was done on a mold for a standard cup shaped part. The wall thickness of the part was .022, the material high density polyethylene. The mold was hot runner construction. Unfortunately the mold was run only on conventional machines with the speeds of operation common a few years ago. This did not give the mold half a chance to show what it could do. As a matter of fact the fastest time that the mold could be operated was a cycle of about eight seconds. The injected material was cooled so fast that an oversize machine had to be used to obtain sufficient injection speed. To further aid the machine the mold had to be run at a temperature of 140°F. Under these conditions the fastest cycle of which the machine was capable was attainable. Another interesting fact was that the mold could be run for about an hour without any cooling in the core. The heat was taken away from the core and cavity and dissipated throughout the mold and the press platen. Studies in the thermal capacity of this mold show it capable of operating on a two to three second cycle with room temperature water.

Another heat control problem sometimes arising in injection molds is in and around hot runner blocks. The heat conductance charts show that stainless is the logical material for hot runner blocks as less heat will be lost or transmitted through this than any other material selected. The function of a hot runner block is not to heat the plastic, but to keep heat in it. Thus stainless is the obvious choice. The same facts are pertinent to insulated runner molds also. Stainless should perform much better than ordinary steel, and permit a longer dwell.

Hot runner molds, both heated and insulated type, need nozzles. The material inside the nozzle must be kept hot, and a minimum amount of heat transmitted through the nozzle to a cavity section of the mold. These specifications are contradictory. The best answer is a nozzle having a core and base of copper, and a shell and tip of stainless. *Figure 3* shows how such a nozzle would look in cross section. Nozzles similar to this have been made, and have proven very effective.

Expenses

Expense must be balanced against the expense of having molds that do not work well, or are very touchy to operate. Experience shows that the best mold that can be built is the cheapest one by the time the order is run off.

A word of caution: Solid copper nozzles will not work. They will chill the moment they touch the mold. Copper will lose its heat as fast as it will take it.

A few comments on some other heat control spots around an injection mold. Stainless sprue bushings will conduct one third of the heat from the nozzle into the mold as will ordinary tool steel. It would appear that runners could be made thinner if stainless runner blocks were used.

On high speed plunger molds for thermosets the judicious use of copper around the anvil under the pot could get heat into the material faster. For example if the heat source is two inches away from the surface of the anvil for a temperature differential of 25°C, about the maximum we should consider, the steel will conduct ½ calorie per square centimeter per sec. If we use ⅝ inch of steel and 1⅛ inches of hard copper under the steel, the anvil will conduct about 1.6 cal./sq. cen/sec. Therefore, the material could be heated about three times as fast.

On extrusion dies copper plating on the outside can be the answer to holding even temperatures over the length of the die.

Other Aspects of Heat Control

Heat barriers in the form of open spaces are often built into molds. Polishing and chrome plating both sides of the open space can very materially increase the insulation effect. Aluminum foil, when shiny, set loosely into these spaces can further improve the insulation. Radiation heat losses can be as important as convection losses.

With regard to metals in general, the more alloying of the base metal, in general the lower the rate of heat conductance. For example pure iron conducts heat as well as beryllium copper. It is the alloying of the steel that brings its conductance rate to less than half. Just as it is the small percentage of beryllium in beryllium copper that reduces its conductance to ¼ that of pure copper. Hardening a metal also reduces its ability to conduct heat.

"Thermal engineering" offers interesting possibilities. Plastics engineers will become more cognizant of these possibilities and begin taking advantage of them. It will mean better molds, better molding machines, and lower cost production.

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Our authors like to hear from readers. Send your comments and questions to Editor, SPE Journal, 65 Prospect St., Stamford. We will forward them to the authors.

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Recent Developments in Rigid Urethane Foams

L. R. LeBras, *Pittsburgh Plate Glass Company*

The development of rigid urethane foams blown with trichlorofluoromethane in place of carbon dioxide was announced in the latter part of 1958. Foam expansion was accomplished in the new process by volatilization of the blowing agent with heat given off by the reaction of isocyanates with hydroxyl groups. Trichlorofluoromethane boils at 74.5°F and is handled by simply blending it into the prepolymer or resin prior to foaming. It is sold under the trade names of Freon 11, Isotron 11, Genetron 11 and Ucon 11. The thermal conductivity of rigid urethane foams blown in this manner is lower than any of the presently used insulating materials. This is shown in *Table 1* which contains a tabulation of k-factors of the common insulating materials.

The improved thermal conductivity of rigid urethane foams blown with trichlorofluoromethane is due to the low k-factor of the blowing agent. A summary of thermal conductivities of gases which affect the k-factor of these foams can be seen in *Table 2*.

Table 1. Thermal Conductivity of Some Building and Insulating Materials (2) k = BTU/(hr.)(ft.²) (°F/in.)

Material	Density lbs./ft.³	°F	k
Asbestos	29.3	32	1.08
Aluminum foil, 7 air spaces/2.5"	0.2	100	0.300
Cork board	10	86	0.300
Felt, wool	20.6	86	0.48
Fiber insulating board	14.8	70	0.336
Fiber glass (3)	0.5	75	0.29
Mineral wool	9.4	86	0.270
Mineral wool	19.7	86	0.288
Polystyrene, rigid foam (4)	1.8	40	0.25
Polyurethane, CO_2 blown	2.3	75	0.24
Polyurethane, CCl_3F blown			
(cut samples, initial)	2.1	75	0.110
(cut samples, fully aged)	2.1	75	0.157
Slag wool	12	86	0.262
Wallboard, insulating type	14.8	70	0.336
Wool, animal	6.9	86	0.252

The low acid number polyester resin and semi-prepolymer previously described produced excellent low k-factor foams in the new process. In addition to having a lower k-factor, the foams are less expensive, due to less toluene diisocyanate being consumed. They also had a lower water absorption and MVT and were less friable at low densities than CO_2 blown foams. The foam properties of a typical polyester blown with CCl_3F and CO_2 are shown in *Table 3*.

Two thermal conductivity values were shown in *Table 3*. The initial k-factor is 0.110. The aged k-factor of 0.157 was run on 12" x 12" x 1" specimens that had been aged at 150°F for over 250 days. Low k-factor rigid urethane foams have a tendency to increase in k-factor until it reaches an equilibrium or plateau value. Actually this was also found to be true for CO_2 blown foams. *Table 4* shows the change in k-factor for cut specimens of both CO_2 blown and CCl_3F blown foams that were aged at 140°F.

The increase in k-factor of the CCl_3F foam seen in *Table 4* is typical of cut specimens being aged in an accelerated manner. The same foam had a k-factor of 0.117 after being aged more than a year in block form at room temperature. This result and many additional k-factor studies indicate a long range of service from low k-factor urethane foams.

Since the thermal conductivity of low k-factor urethane foam does increase to an equilibrium value, it is important to know some of the variables which influence these changes. The first factor to be discussed is foam density. *Table 5* shows k-factor retention data at several different densities for the same resin system.

The initial k-factor and aged k-factor were lowest for the 2 lb./ft.³ foam. Lowering the foam density resulted in slightly higher initial k-factors and equilibrium k-factors.

The k-factor of rigid urethane foams is dependent upon the cell structure of the finished foam. In general, a fine and uniform cell structure is desirable. This is best achieved by mixing the formulation in a foam machine. "Hand" or batch mixing does not produce as fine or as uniform a cell structure as machine made foam. This point is illustrated in *Table 6* in which k-factor data are shown for three different resins which were mixed by machine and by hand.

Table 2. Thermal Conductivity of Gases and Vapors (5) k = BTU/(hr.) (ft.²) (°F/in.)

Substance	°F	k
Air	32	0.168
Carbon dioxide	32	0.102
CCl_3F (6)	32	0.058
Nitrogen	32	0.168
Oxygen	32	0.170
Water vapor	115	0.144

Although machine mixed foams had a lower initial and aged k-factor, the increase in k-factor on aging was less for hand mixed foams. This fact is attributed to much higher initial k-factors of hand mixed foams. Such high initial k-factors indicate that partial equilibrium with air had already taken place.

them in stoichiometric ratio. Some shorter range k-factor retention data, as is seen in *Table 9*, indicate that such reactions are more favorable than those having excess prepolymer.

The most recent development in this field is the use of polyether resins in rigid urethane foams. Because they cost less than polyesters, polyethers are being studied in an attempt to equal or exceed the properties of polyester type foams. The procedure for making rigid foams with polyethers is similar to polyesters, and in some cases the same foam formulation can be used. Both CO_2 blown and low k-factor foams can be made from polyether resins. A summary of foam properties from a typical trichlorofluoromethane blown polyether type urethane is given in *Table 10*.

In general, polyether properties are almost equal to polyester properties. The polyesters hold an edge in strength properties, water absorption and temperature serviceability range. The polyethers have a slightly higher molded density and require a longer cure than polyester type foams. The k-factor retention and percent closed cells of polyethers are equal to polyesters. Polyethers are superior in ease of handling due to their lower viscosity and improved compatibility with the blowing agent. For many applications, the polyether foam properties shown in *Table 10* will be more than adequate. Further improvements are expected which should result in wide acceptance of these resins in rigid foams.

Table 3. Foam Properties of Typical Polyester Blown with CCl_3F & CO_2

	CCl_3F Blown	CO_2 Blown
Density	2.1 lbs./ft.³	2.3 lbs./ft.³
Closed cells	91%	89%
Compression strength, 10% deflection	38 psi	37 psi
Tensile strength	47 psi	60 psi
Flexural strength	50 psi	71 psi
Water absorption	0.040 lbs./ft.²	0.069 lbs./ft.²
MVT	1.0 perms	1.7 perms
K-factor, initial	0.110 BTU/(hr). (ft.²) (°F/in.)	0.24 BTU/(hr.) (ft.²) (°F/in.)
K-factor, aged	0.157 BTU/(hr.) (ft.²) (°F/in.)	
Dimensional stability		
—25°F to 225°F (linear change)	less than 5%	less than 5%
95% R.H., 150°F (linear change)	less than 5%	less than 5%

One of the most important advantages of urethane rigid foam is the fact that it can be foamed in place with excellent adhesion to a wide variety of substrates. This procedure eliminates the need for large storage areas for foam and reduces fabrication costs. The density of molded foams are usually about 20 to 30 percent higher than the same foams in free or open expansion. This is primarily due to the restriction affect that the walls of the mold have upon the foaming mixture. The k-factor retention of free blown and molded foams were investigated. The results for a low density and a medium density machine run are tabulated in *Table 7*.

The superior k-factor retention of molded foams cannot be attributed to density alone. The 1.6 lb./ft.³ formulation molded to a density of 2.1 lbs./ft.³ is appreciably better in k-factor retention than the 2.0 lb./ft.³ open blow foam. This improvement in k-factor retention is believed to be due to thicker cell walls of molded foams.

All resins used in the preparation of rigid urethane foams do not have equal k-factor retention. This is illustrated in *Table 8*, in which a typical polyester resin is compared to a resin having a low number of cross-linking sites and another resin which had poor compatibility with trichlorofluoromethane and toluene diisocyanate.

Another factor that influences k-factor retention is the manner in which the resin component and prepolymer component are formulated. The usual practice is to combine

Table 4. Thermal Conductivities of Rigid Urethane Foams k = BTU/(hr.) (ft.²) (°F/in.)

Aging in days @ 140°F	CO_2 Blown	CCl_3F Blown
0	0.186	0.112
7	0.222	0.128
14	0.233	0.136
21	0.237	0.140
28	0.238	0.144
50	0.239	0.149
100	0.24	0.155
150	0.24	0.156
200	0.24	0.157
250	0.24	0.157

Table 5. Effect of Foam Density upon k-factor Retention

Density (lbs./ft.³)	k-Factor, Initial	k-Factor, Aged (Equilibrium @ 140°F)
1.42	0.129	0.181
1.60	0.122	0.160
2.0	0.118	0.152

Table 6. Influence of Mixing Method on k-Factor

Resin	Mixing Method	k-Factor, Initial	k-Factor, Aged (Equilibrium @ 140°F)
A	machine	0.116	0.150
A	hand	0.157	0.180
B	machine	0.118	0.160
B	hand	0.163	0.178
C	machine	0.121	0.159
C	hand	0.144	0.170

Table 7. Effect of Foam Expansion Type on k-Factor Retention

Density (lbs./ft.³)	Type	k-Factor, Initial	k-Factor, Aged (Equilibrium @ 140°F)
1.6	free	0.122	0.178
2.1	molded	0.109	0.155
2.0	free	0.118	0.170
2.5	molded	0.106	0.150

Table 8. k-Factor Retention of Various Resins

Resin Type	Density	k-Factor,[1] Initial	k-Factor, Aged (Equilibrium @ 140°F)
Typical polyester resin	2.0	0.110	0.155
Low cross-linking resin	2.0	0.110	0.180
Incompatible resin	2.0	0.124	0.203

Table 9. Influence of Foam Formulation on k-Factor Retention

Formulation	Density	k-Factor, Initial	k-Factor, Aged (40 days @ 140°F)
Stoichiometric	2.1	0.104	0.132
Excess prepolymer	2.1	0.110	0.143

Due to their improved mixing ability, "one-shot" polyether rigid foam formulations are being investigated. It is more economical to make one-shot foams and it avoids having to set up equipment for cooking prepolymers. The "one-shot" foams thus far have not equaled prepolymer foams in properties. They also are much more toxic than prepolymer formulations.

Table 10. Foam Properties of Typical Polyether Blown with CCl_3F (molded)

Density (open blow)	2.0 lbs./ft.³
Density, molded	2.5 lbs./ft.³
Closed cells	93%
Compression strength, 10% deflection	32 psi
Tensile strength	30 psi
Flexural strength	55 psi
MVT	1.7 perms
k-factor, initial	0.110 BTU/(hr.) (ft.²) (°F/in.)
k-factor, aged	
Water absorption	0.062 lbs./ft.²
(equilibrium	
@ 140°F)	0.160 BTU/(hr.) (ft.²) (°F/in.)
Dimensional stability	
—25°F to 200°F (linear change)	less than 5%
95% R.H., 150°F (linear change)	less than 5%

Rigid urethane foams will support combustion when they are ignited. Self-extinguishing products have been made with polyester type foams by the use of additives. The most effective additives are antimony oxide, ammonium phosphate and chlorinated phosphate plasticizers. The first two materials are solids and are difficult to process. They produce slightly higher foam densities and some of the foam properties are not as good as conventional foams. Plasticizers usually aid resin processing by reducing resin viscosity, but foam density is increased. Foams containing plasticizers are limited in their usefulness because properties such as heat distortion point, hydrolytic aging and water absorption are poor. Polyether type foams are more difficult to flame retard than polyesters. At the present time, investigations of reactive type flame retardants are being made to produce a "built-in" flame retardant urethane polymer. Although this approach is of a long range nature, some of the preliminary results indicate that a flame retardant foam is possible.

The major application for low k-factor rigid urethane foams is to provide thermal insulation for household refrigerators and related products, in refrigerated railway cars, and in trailer bodies. They are being used in marine flotation and buoyancy equipment and to fill voids in ships because of their low water absorption characteristics. Due to their foam-in-place ability with excellent strength at low densities, door and building panel cores are a natural application. Uses are also being found in packaging and in a variety of smaller applications. Development of an acceptable flame retardant rigid urethane foam will open up the entire building and construction field to these products.

Acknowledgment

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Cause Of Melt Fracture

How it is Related to Extrusion Behavior

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Experimental results providing useful and practical design data for the entrance geometry of extruder dies.

High-speed extrusion of polymers in the form of wire covering, sheet or film, and filaments often produces a rough or irregular surface, beginning at a critical shear rate (1-10). This effect has been attributed to the fracture of the melt in the extrusion die. No satisfactory explanation for this melt fracture has been advanced, so its elimination has required an empirical approach.

A qualitative modification in the theory of viscoelastic flow is proposed. This modification provides an explanation of melt fracture and other flow phenomena, such as the capillary end effect and melt-index recovery or "pop-up". A new mechanical model for viscoelastic flow was designed and it graphically illustrates the various aspects of this theory. *On the basis of this modification, it is predicted that, as the shear rate of most plastic materials is rapidly increased—for example, at the entrance to a capillary—abnormally high initial stresses are required because (1) energy must be supplied to decrease the viscosity and (2) the initial high viscosity requires a certain amount of time to decrease to its equilibrium value, which is low at high shear rates.* Melt fracture occurs when the shear stress exceeds the shear strength of the melt, and thus is most likely to occur where a sudden increase in shear rate takes place. Melt fracture depends on the strength of the melt, the rate of increase of shear rate (not shear rate alone), and the viscosity breakdown factors (energy and time) for the melt.

Experimental measurements of viscosity breakdown energy and time and of critical shear rates at various rates of increase of shear rate were made in order to test the theory. Data from these experimental measurements were used in calculating entrance geometry of dies for maximum rates of smooth flow. Consideration was given to the application of these data in designing other extrusion, molding, and mixing equipment where, in some cases, melt fracture may be a desirable feature. Some other methods of controlling irregular extrusion were also considered.

Theoretical Considerations

When a shearing stress S is applied to a viscous fluid, the fluid is sheared or flows at a constant rate $\dot{\gamma}$. The shear stress and shear rate are related to each other according to equation

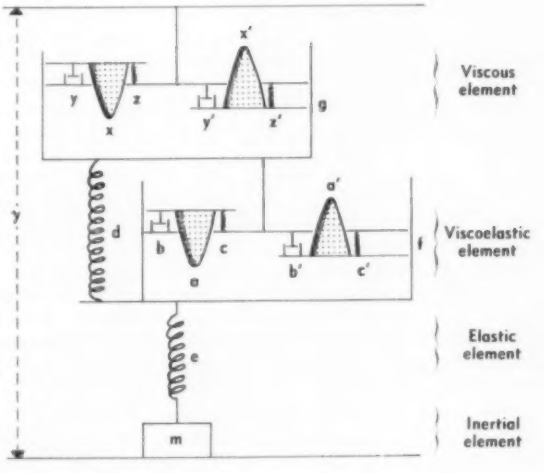

Figure 1. Mechanical Analog for Viscous Flow or Deformation.

$$S = \dot{\gamma}\eta \qquad (1)$$

where η is the proportionality constant or viscosity of the liquid. For most liquids under ordinary conditions, η is constant and the liquids are called Newtonian; however, for most synthetic resins η is not constant but decreases with increasing shear rate or shear stress.

Bueche (see Fox, 11), Eyring (Fox, 11) (12), Flory (Fox, 11), Pao (13), Mooney (14), and others have developed theories which rather accurately describe the flow of a non-Newtonian material in a steady state of flow and at fairly low shear stresses. However, in many industrial processes—for instance, during extrusion—the shear stress is neither steady nor always low.

Eyring and Bueche (see Fox, 11) considered the flow of a polymeric material to take place as the result of jumps of a segment of a molecule. Since no primary bonds are broken, cooperation between segments is necessary. Molecular chain entanglements and secondary bonds require more extensive cooperation, which contributes to a flow resistance. Application of a shear stress to the system causes flow to take place. Greater stress causes a higher rate of flow and also disentangles some chains and breaks some secondary bonds. Greater stress also causes orientation of nonspherical flow units. These three factors—disentanglement, orientation, and breaking of secondary bonds—all contribute to a higher rate of flow than would be expected for a given increase in shear stress. Thus, since the viscosity is defined as the ratio of shear stress to shear rate, the viscosity decreases as the shear stress or shear rate increases. This is the reason for pseudoplastic or thixotropic flow.

It is reasonable to assume that a certain amount of time and energy for the operation of these three "breakdown" mechanisms is required. The energy is absorbed as an apparent resistance to flow when shear stress is first applied. Then as a constant stress or rate of flow is continued, no further degree of disentanglement, orientation, and breaking of secondary bonds takes place; thus, an equilibrium is reached. However, if the shear stress is relaxed, the viscosity increases quite rapidly in the case of pseudoplastic materials, and reapplication of the stress involves the same magnitude of breakdown energy and time.

In addition to being a viscous liquid, the molten resin also is somewhat elastic in nature. This elasticity is probably caused by the distortion or displacement of an entangled molecule or segment. Part of this elasticity may be simple—that is, the response is instantaneous—and part of it may be a retarded elasticity—that is, the rate of the elastic response may be controlled by viscous flow. The viscous element of the retarded elasticity may also be non-Newtonian in nature.

This complicated flow picture is somewhat difficult to visualize completely. To aid this visualization, a phenomenological treatment is often used with the aid of theoretical analogs such as Voigt or Maxwell models or combinations thereof (15). However, these models do not provide a full picture of non-Newtonian flow. A new model was developed which makes use of pure Newtonian fluids and mechanics to describe non-Newtonian behavior and the concept of a breakdown time and energy. This model, shown in *Figure 1*, at first appears somewhat complicated; however, this model is sufficient in itself to describe non-Newtonian flow or deformation covering a wide spectrum of relaxation times without using the customary long series of similar models, each having slightly different constants.

The model has four primary elements. Of course, it is assumed to be operating in an ideal state; that is, gravity and mass are absent (except for M), dash pots are frictionless, springs are Hookian (unless otherwise specified), and bars between elements remain paralleled to the base. If a stress is applied at M either toward or away from the base, the rate of flow or deformation is represented by the rate of motion of M or rate of change of γ $\left(\text{that is, } \frac{d\gamma}{dt}\right)$, which is controlled by the functions of the various elements.

The novel feature of this model is the use of a valve in the dash pots. Each valve consists of a "needle" operating in a short, circular hole. The motion of the needle is controlled by a spring and a dash pot and the hydrostatic pressure on the needle. Thus, when the piston moves, fluid in the dash pot flows only through the annular space around the needle. (As a further condition of the ideal state, the absence of kinetic energy effect, turbulence, and other abnormal flow restrictions may be assumed.)

In a molten material or a solution, the viscous element is the most important. An upward force applied at M causes pressure to develop in dash pot g, which, in turn, provides an upward thrust to needle x. At constant stress, needle x assumes an equilibrium position (controlled by the modulus of the z spring). The rate of approach to this position is determined by the constant of dash pot y. A downward force operates needle x' in a similar fashion. The change in flow restriction as the position (or stress) is changed, is determined by the shape of the needle. This restriction corresponds to the viscosity of the system.

It is obvious that an application of a greater stress or rate of deformation to this model causes a further opening of the valve, which further reduces the flow restriction (viscosity). This corresponds to non-Newtonian flow of a pseudoplastic type. Since the valve at x requires a finite time to retract when the stress is relaxed, this model may also show thixotropic behavior. If needle x were a cylinder or z had a very high modulus, Newtonian flow would result. If needle x were inverted, the result would simulate rheopectic or dilatant flow.

The viscosity of dashpot y and the modulus of spring z determine the relaxation time for needle x. The distance that x moves under an applied stress determines the energy required. Thus, breakdown energy and breakdown time correspond to the energy and time required to open the valve. These, in turn, correspond to the energy and time required to orient, disentangle, or break secondary bonds of the molecules or flow units. The amount of viscosity breakdown is simulated by the increase in size of the annular opening.

It should be pointed out that this model applies to a small increment of the melt; for instance, when pressure is

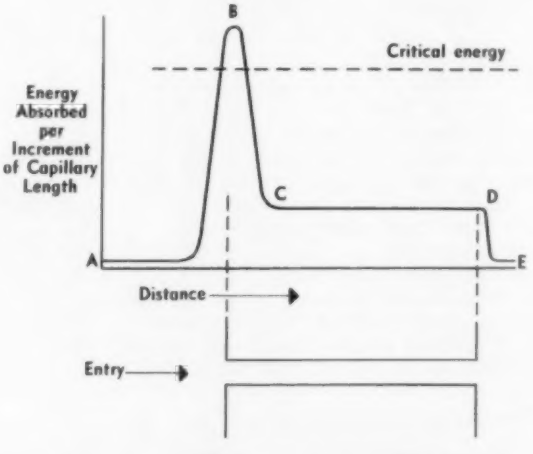

Figure 2. Profile of Energy Absorbed Throughout the Length of a Capillary on Extrusion of Polyethylene at a Given Pressure.

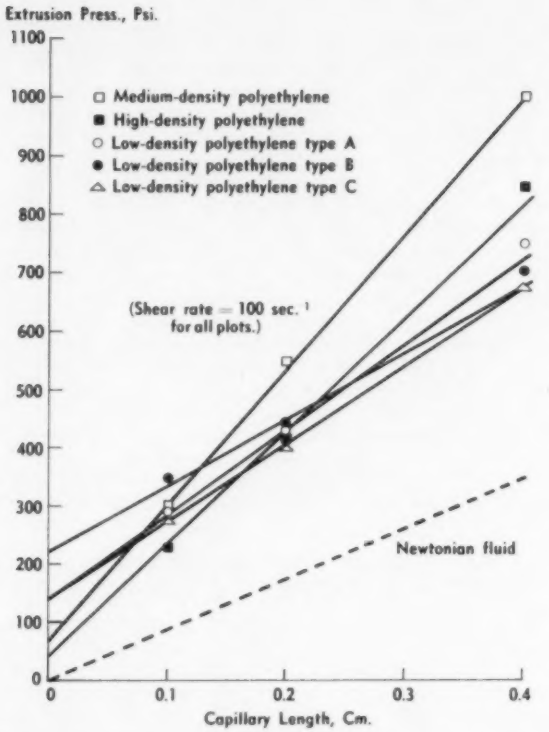

Figure 3. Effect of Capillary Length on Extrusion Pressure for Various Polyethylenes.

applied to a melt to force it through a capillary, the melt is sheared only as it passes through the capillary. Thus, a given increment of the melt is under high shear stress only while it is in the capillary.

If γ represents the total length of the model, $\left(\frac{d\gamma}{dt}\right)$ represents the rate of shear. In a capillary rheometer, where the melt reservoir is under a constant pressure, $\left(\frac{d\gamma}{dt}\right)$ is constant for the increment of melt inside the capillary; however, the shear stress will follow the energy profile shown in *Figure 2*. If compression of the model begins at a given rate, the initial force must be very high because the valves are nearly closed. Thus, much of the force is used to compress spring *e*. As valve *x* opens, true fluid flow occurs and spring *e* may relax somewhat. When needle *x* reaches the equilibrium position, the shear stress becomes constant until the shear rate is discontinued (end of capillary is reached). Since *e* does not relax completely while the melt is in the capillary, the model recovers somewhat (expands) as the force is removed. This corresponds to the "melt index recovery", or "pop-up", as the melt emerges from the capillary. Clegg (8) found that in very short capillaries the pop-up was abnormally high for a particular shear rate. In this case, the needle and elastic element *e* had not reached equilibrium.

If $\frac{d\gamma}{dt}$ or $\frac{d^2\gamma}{dt^2}$ are high enough, the high stresses required will cause the model to rupture. This corresponds to the melt fracture or slip which produces irregular flow in polymer melts. When the melt fractures under a shearing stress, flow occurs through a sort of "slip-stick" process which relieves the high stress. Thus the melt in this small area tends to flow faster than that in an adjacent area. This causes a turbulence to develop both behind and in front of the fractured portion. Rough extrusion then occurs when the shear stress becomes high enough to cause a shear rupture or possible cavitation in the melt. This corresponds to the breaking of a fiber or molded test specimen when an applied tensile stress becomes too high. Fracture should occur at the point of maximum shear stress and, according to this model, this maximum stress should occur at the entrance to the capillary, or at *B* in *Figure 2*. This means that the magnitude of the breakdown energy is related to the maximum shear stress.

Thus, the critical shear rate would be expected to correlate with the breakdown energy. It may be possible to estimate this breakdown energy if one could extrapolate the horizontal portion of the curve in *Figure 2* back to a point representing the capillary entrance. In practice this might be done by plotting for a given material, at constant shear rate, the pressures required to maintain a constant shear rate at various lengths of capillary, according to the following equation (see Appendix 1):

$$P = P_e + 1\left(\frac{2}{r}\eta\dot{\gamma}\right) \qquad (2)$$

where P is the pressure; r is the capillary radius; η is viscosity; $\dot{\gamma}\left(\text{or } \frac{d\gamma}{dt}\right)$ is the shear rate; l is the capillary length; and P_e is that portion of the pressure required to overcome the breakdown factors. Plots of this type (P vs. l) are shown in *Figure 3* for a wide variety of types of polyethylenes. These plots are straight lines since η, $\dot{\gamma}$, and r are constant. The intercept on the pressure axis is P_e. Bagley (5) reported similar plots but interpreted them somewhat differently. The breakdown energy in calories per gram may be calculated by multiplying P_e by the volume of one gram of extruded material, converting, of course, to the appropriate units. The magnitude of this intercept shows that for fairly short shearing times the energy or stress requirements for the breakdown mechanism are large, compared to the total energy requirements.

Experimental Results and Applications

Table 1 shows the correlation, calculated at 100 sec.$^{-1}$, between critical shear rate and the breakdown energy of some polyethylenes. The agreement is excellent in spite of the fact that the melt strength is also a factor in melt fracture. As the shear rate increases, the slope of the plots in *Figure 3* increases and P_e increases. However, P_e increases with increasing shear rate much slower during rough flow

Table 1. Breakdown Energies of Some Polyethylenes

	Moderate Shear Rate		
	Breakdown Energy, Cal./G.		Critical
Identification	100 Sec.$^{-1}$	1000 Sec.$^{-1}$	Shear Rate[a]
Low-density polyethylene A	0.5	1.0	100
Low-density polyethylene B	0.35	—	200
Low-density polyethylene C	0.35	—	150
Medium-density polyethylene	0.15	—	~ 900
High-density polyethylene	0.11	0.5	~1100

[a] Capillary entrance, 180°.

than it does during smooth flow. The strength of the melt might be measured by measuring P_0 at the critical shear rate.

Metzner (9) and others have implied that roughness depends primarily on rate of shear. However, the above theory and model would indicate that if the shear rate is reached at a slow rate— that is, $\frac{d^2\gamma}{dt^2}$ is low—roughness either does not occur or starts at a much higher shear rate. A slow approach to a given shear rate may be accomplished in a capillary rheometer by using a conical entrance *(see Figure 4)*. The rate of increase in shear rate $\left(\frac{d^2\gamma}{dt^2}\right)$ decreases as the cone angle decreases; therefore, it would be expected that the smaller the cone angle the higher the critical shear rate. This is shown to be the case by the solid curve of *Figure 5*. Similar data were reported by Clegg (8) and others (2).

It is necessary that a small angle cone be long enough that its entrance is of sufficient diameter to prevent the rate of flow from exceeding the critical shear rate at the cone entrance. The rheologically ideal entrance would be a cone with infinitely small angle of infinite length. Obviously, this is impractical, so it is necessary to compromise by carefully programming the rate of increase of shear rate. Thus, greater efficiency is obtained by using a cone of somewhat larger angle at the entrance to the primary cone. Efficiency may be improved still further by using a series of cones of decreasing angle or a properly designed horn shape for the capillary entrance.

Polymers with different molecular structures require different programs as determined by the entrance geometry of the capillaries. This entrance geometry may be calculated for any particular resin by obtaining for the resin a curve similar to that shown in *Figure 5*. This particular curve was obtained using a small laboratory rheometer and a set of capillaries having different entrance angles. These capillaries must be very carefully made according to specifications and have no burrs or surface irregularities. Both irregularities in the die and nonhomogeneous melts may cause localized high $\frac{d^2\gamma}{dt^2}$, which may lead to rough extrudate.

The dashed curve of *Figure 5* was obtained by applying a drawing tension to the extrudate during extrusion. Apparently, if the extrudate is not too rough, it may be smoothed out by applying the proper draw tension. If the tension is too high, the extrudate breaks. This drawing was done by hand. A mechanical windup device would be expected to give a somewhat higher critical shear rate because the tension would be constant and could be adjusted more critically. This device would cover a much wider range of high shear rates also.

A simple way of calculating entrance geometry from such a curve is as follows. Assume drills are available to make several different tapers, having half-angles of say 3°, 12°, and 30°. The maximum shear rate for a half-angle of 3° may be read from the curve. This rate determines the minimum exit diameter for a desired rate of flow Q $\left(\dot{\gamma} = \frac{4Q}{\pi r^3}\right)$. The length of the 3° section is determined by the exit size required by the 12° taper, which is calculated from Q and the appropriate reading from the curve. The same procedure may be used to calculate the lengths of the 12° and 30° tapers (see Appendix 2).

The double-tapered die shown in *Figure 6* was calculated for a specific low-density polyethylene. This resin began to roughen at a shear rate of 150 sec.$^{-1}$ in the ordinary flat-entry die. With the new die, extrusion was smooth at a shear rate of 13,000 sec.$^{-1}$. By using these design techniques, extrusion was improved in production-size dies for both sheet and rod.

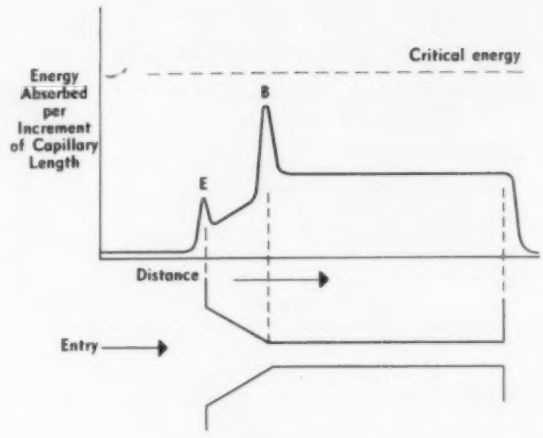

Figure 4. Profile of Energy Absorbed Throughout the Length of a Capillary With a Cone-Shaped Entrance.

An increase in temperature or a decrease in molecular weight of a resin will decrease the stress required for extrusion at a particular shear rate. Therefore an increase in critical shear rate under these conditions would be expected and was actually found.

The length of the capillary itself is determined by several factors, including (1) the pressure drop desired, (2) the importance of controlling the melt expansion (or "pop-up") at the exit, and (3) space requirements. Items (1) and (3) are easily determined by conventional methods. However, the melt expansion, caused by elastic recovery, may be somewhat more difficult to predict by the usual methods and, in that case, experiments based on the new flow model provide useful data.

Elastic recovery is important because it is one of the factors controlling the diameter or thickness of the extruded rod or sheet. It is probably caused by normal stresses which are the direct result of the elastic deformation of the melt in the direction of extrusion. Referring to the model, elastic recovery is then caused by the recovery of springs *e* and *d*. Thus, the amount of expansion should follow the energy diagram of *Figure 2*. Qualitatively, this is supported by data reported by Clegg (8) and others. The amount of elastic recovery was found to be constant except in short capillaries, where the amount of recovery increased with decreasing length. The time required to reach a steady state depends on the relaxation time of the spring and dash pot controlling valve *x*. On the basis of elastic recovery data on extrusions through very short capillaries, this time appears to be of the order of 0.2 sec. for polyethylene, which is in qualitative agreement with measured relaxation time of the melt (8).

At moderate to high rates of extrusion, the length of the capillary is important in the control of extrudate thickness because the melt is in the capillary for a time that is shorter than the relaxation time. Of course, the extrudate may be drawn down, but this is limited in an elastic melt because, if the drawing tension is too great, fracture occurs. On the other hand, if draw-down tension is being used to reduce roughness, the appropriate amount of recovery (or die diameter) is required so that, when the extrudate is drawn to the proper size, the tension will be high enough to remove the roughness.

If the geometry of a die is known, it is fairly easy to calculate the time-shear pattern. A laboratory rheometer may

be provided with a set of dies (preferably with tapered entrance) of varying length, so that the melt recovery may be measured as a function of shear time. A plot of these data at different shear rates provides a fairly complete picture of the elastic recovery of a melt. Curves must be determined for each type of polymer, because there is considerable variation in melt elasticity even among the polyethylenes. From these data the geometry may be calculated for a die which will provide the desired melt recovery.

These factors are very important in high-speed extrusion where a large amount of draw-down is involved, for example, in wire coating. In this case the die entrance geometry should provide a minimum of breakdown stress. The length and diameter of the land of the die should be designed to provide the optimum tension, so that the draw-down will be sufficient to smooth out roughness and yet not pull fracture into the melt. Actually, most high-speed wire coating takes place under conditions of rather severe melt fracture in the die. The expected roughness does not occur because of the tension applied by drawing the wire. The fracture probably causes die drool. Thus, if the resin used is not the one for which the die was designed, it should not have an appreciably higher or lower melt recovery; otherwise, a rough extrudate may be obtained.

Some Beneficial Effects of Melt Fracture

It was stated earlier that melt fracture provides a sort of relief mechanism for viscous flow. Actually, at constant shear stress or pressure drop, the flow rate is higher under conditions of fracture than under conditions of smooth flow. Bagley (6) reported an increase in flow rate by a factor of three for a particular polyethylene. In our study, a twenty-fold increase in flow rate was measured in changing from smooth to rough flow at constant shear stress.

This apparent decrease in viscosity may be of considerable help in certain processing operations; for instance, in injection-molding, a mold may be filled very rapidly under conditions of melt fracture and then the fractured melt will "heal" under pressure. This permits a fast molding cycle with a high-viscosity material. In an extruder barrel it may be desirable to have melt fracture occur in the space between the screw land and the barrel wall. This would tend to reduce the work required to turn the screw and thus minimize polymer degradation. Conditions for causing melt fracture may be achieved by calculating the design of the shearing surfaces, using the same data that were used in the calculations for eliminating melt fracture.

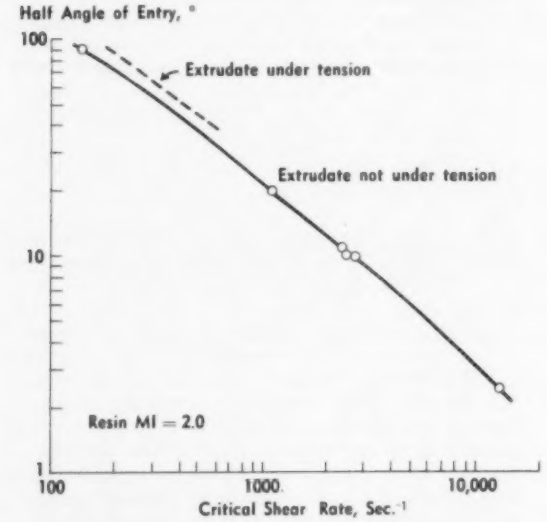

Figure 5. Effect of Capillary Entry Angle on Critical Shear Rate at 190°C.

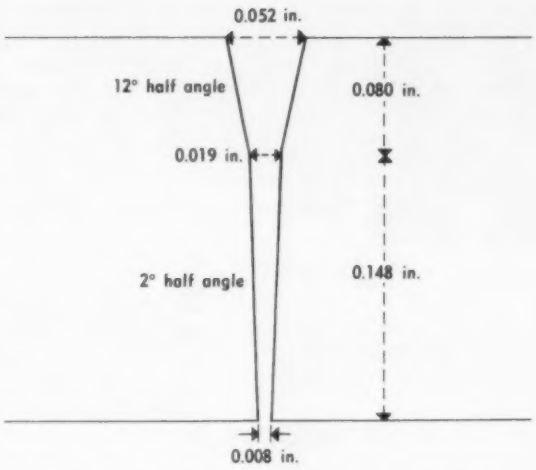

Figure 6. Tapered Capillary for Smooth, High-Speed Extrusion of Polyethylene.

Mixing

The "breakdown energy" concept may be applied to more efficient design of mixing equipment, particularly with respect to fine-scale mixing or homogenizing, for which most commercial equipment is rather inefficient (16). Thorough, fine-scale mixing requires a fairly high rate of shear, which involves an appreciable breakdown energy. In most equipment (extruder screws, Banbury, etc.) the high shear rate is applied to a particular increment of melt in an intermittent fashion. Each application of the high shear rate requires extra energy for the "breakdown" mechanism. Since the time of shear is usually very short, the "breakdown" energy requirement for mixing may be very large. This energy is wasted with respect to mixing.

Thus, the most efficient type of fine-scale mixing would be one in which each increment of melt is under a high shear rate only once but for a comparatively long time. This might be done by designing an extruder screw so that macro-scale premixing would take place in the screw section and then fine-scale mixing would take place in a section consisting of a rotating drum with a small gap between its surface and the surface of the barrel. A screw feed on a "Maxwell" type extruder might accomplish this type of mixing.

Dispersion of pigments may require the opposite approach. For this purpose, very high stresses are required to disintegrate the pigment. These stresses may be developed by causing many rapid changes in shear rate to take place at stresses just under that required for melt fracture.

APPENDIX 1

Derivation of Equation Relating Pressure to Capillary Length

The Poiseuille equation for Newtonian flow through a capillary is as follows:

$$S = \eta\dot{\gamma} = \frac{Pr}{2l}$$

where S is the shear stress, $\dot{\gamma}$ the shear rate, η the viscosity, P the pressure required to force melt through the capillary, r the capillary radius, and l the length. Rearranging,

$$P = \left(\frac{2}{r}\eta\dot{\gamma}\right) l.$$

This is the equation for a steady state of shear. However, according to the "breakdown" energy idea, extra energy or pressure is required to achieve the steady state conditions. This pressure, P_o, is then added to the steady state pressure to obtain the total pressure required to force a melt through a capillary at a specified shear rate.

Thus,

$$P = P_o + \left(\frac{2}{r}\eta\dot{\gamma}\right) l \qquad (2)$$

At constant $\dot{\gamma}$ the η is constant and equation 2 becomes the equation of a straight line plot of P vs. l with an intercept of P_o.

APPENDIX 2

Sample Calculation of Entry Geometry of a Capillary

Assume that facilities are available for making conical holes having half-angles of 3°, 12°, and 30° and that the most efficient entry geometry for extruding the resin described by Fig. 5 is desired for a die with an exit diameter of 0.2 cm.

The critical shear rate for an angle of 3° is 10,000 sec.$^{-1}$, giving an extrusion rate $Q = \frac{\dot{\gamma}\pi r^3}{4} = \frac{10{,}000 \times \pi(0.1)^3}{4}$ = 7.9 ml./sec. The critical shear rate for an angle of 12° is 2100 sec.$^{-1}$. For a flow rate of 7.9 ml./sec. the radius r must be $\sqrt[3]{\frac{4Q}{\pi\gamma}} = \sqrt[3]{\frac{4 \times 7.9}{\pi \times 2100}} = 0.168$. Thus, the 3° taper must be long enough to have an entrance radius of 0.168 cm., or an increase of 0.068 cm. Length $l = \frac{0.068}{\tan 3°}$ $= \frac{0.068}{0.018} = 3.8$ cm.

The lengths of the 12° and 30° tapers may be calculated in the same way, using the same flow rate of 7.9 ml./sec.

The volume of the 3° taper section (cone frustum) is 0.056 ml. Then the average residence time of a portion of the melt in this taper at the maximum rate of smooth extrusion is $\frac{0.056}{7.9} = 0.007$ sec., or about 1/30th the breakdown time of 0.2 sec. Thus, the equilibrium viscosity is not achieved in the taper and cannot be reached without an impractically long capillary.

APPENDIX 3

Comments on article by W. Philippoff and F. H. Gaskins, "The Capillary Experiment in Rheology," in "Transactions of the Society of Rheology," Vol. II, R. D. Andrews, Editor, Interscience Publishers, Inc., New York, N. Y., 1958, pp. 263-284.

Since this article was written, Philippoff and Gaskins have published a paper on extrusion of viscoelastic materials through capillaries. They attribute the high "entrance" energy to the energy required to distend the elastic element. Their ideas explain a significant part of the energy involved and are more or less implicit in the "breakdown energy" concept. Certain discrepancies between experimental work and the "elasticity" concept, however, lead to the conclusion that the broader concept of "breakdown energy" is desirable.

It was stated by Philippoff and Gaskins that the elastic distention is instantaneous; however, in high-speed extrusion it is likely that it would require an appreciable fraction of the time involved. This should lead to the prediction that the amount of elastic recovery would be constant or would *decrease* with shorter capillaries. Actually, elastic recovery *increases* in very short capillaries.

According to Philippoff and Gaskins, there should be a high correlation between the elasticity of the melt and the value of the intercept on the pressure axis of the plot of pressure versus capillary length at constant shear rate. This is true for a group of polyethylenes of the same type; however, for widely differing types, such as those shown in *Figure 3*, the correlation is very poor. Our measure of elasticity (recoil method) was not very precise, but it was more than adequate for ranking these five polymers. Measurements of molecular expansion factors on these polymers predict the order of elasticity as shown. These polymers may be ranked in order of increasing intercept and elasticity as follows:

Intercept—high-density < medium-density < low-density, type C = low-density, type A < low density, type B.

Elasticity—low-density, type A <<< low-density, type C < low-density, type B < medium-density < high-density.

It is obvious that the magnitude of the intercept involves more than a consideration of elasticity.

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An Analysis of Injection Mold Filling of Polyethylene

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Union Carbide Plastics Co.

The brief period when material is flowing into the mold cavity is of major importance in injection molding. The behavior of the material during this period plays a major role in determining the physical properties of the molded article as well as the molding production rate.

There have been numerous investigations concerning the factors of mold filling which affect the strength and appearance qualities of injection molded articles. However, other than the original work of Spencer and Gilmore (1) and the recent work of Ballman, et al (2) there has been only rather limited study given to determining the fundamental mechanisms of polymer flow in injection mold cavities. This undoubtedly has been largely due to the inherent complexity of analyzing the flow of hot polymer through a cold mold cavity.

In the following study, it was found that under certain conditions the complexities of mold filling can be simplified, and mold filling lends itself to analysis in terms of existing flow theory. The main purpose of this paper is to provide a simplified analysis of mold filling. The information is intended to serve as a guide concerning the effects of mold dimensions, mold fill-out patterns, process variables, and certain material variables on the mold filling behavior of polyethylene.

Analysis Under Machine-Controlled Flow Conditions

In previous investigations (1 and 2), it was found that two basic types of flow can occur during mold filling. Ballman, et al chose to call these "die-controlled flow" and "machine controlled flow". The so called die-controlled flow occurs when the injection pressure setting is reached before the mold is completely filled. It is easy to recognize this type of flow in a molding operation simply by observing the injection ram travel. When the ram slows down prior to the completion of its stroke, die-controlled flow is occurring. When this happens, the mold is being filled under conditions of constant pressure and ever decreasing flow rate.

"Machine controlled flow" occurs when the injection pressure setting is not reached until the mold is completely filled. In this type of flow, the injection ram moves at a constant rate for its entire stroke. Thus under these conditions, the mold is being filled at constant volumetric flow rate and increasing pressure.

The following analysis of the mold filling behavior of polyethylene is performed under conditions of "machine controlled flow". Whereas the study is limited to this extent, it is felt that a major part of the commercial polyethylene injection molding is performed under these conditions. In support of this, it has been observed that even a difficult molding job such as a 22 gallon garbage can in commercial production is filled under machine controlled flow conditions.

Mold Filling Relations

The mechanisms of polymer flow through an injection mold cavity are very similar to those through extrusion dies. In a recent analysis of extruder performance (3), polymer flow through extrusion dies was defined as follows:

$$(1)\quad Q = \frac{P}{Kn} \quad \text{or} \quad P = KnQ$$

where Q = the volumetric flow rate, $in^3/sec.$
P = the pressure drop across the die, psi
n = the effective resin viscosity, $\frac{lb\text{-}sec}{in^2}$
K = the die flow resistance constant, in^{-3}

This relation assumes steady state flow conditions.

To apply this relation to injection mold filling, the basic assumptions of steady state flow must be met. Mold filling in injection molding consists of a hydraulically driven ram forcing material through a heating cylinder and subsequently into a cold mold cavity. Under conditions of machine controlled flow, the injection ram forces polymer through this system at a constant volumetric flow rate. To further satisfy steady state flow conditions, it must be assumed that cooling of the material during mold filling can be neglected. Later in this paper it will be shown that under normal commercial molding conditions the cooling of low density polyethylene during mold filling is minimized, and this assumption is valid.

Therefore, relation (1), converted to injection molding terminology, defines mold filling under machine controlled conditions as follows:

$$(2)\quad Q = \frac{P}{Kn} \quad \text{or} \quad P = KnQ$$

where Q = the volumetric rate of filling, determined by ram diameter and ram speed, $in^3/sec.$
P = the pressure applied at the mold entrance, psi
n = the effective resin viscosity, $\frac{lb\text{-}sec}{in^2}$
K = the mold flow resistance factor, in^{-3}

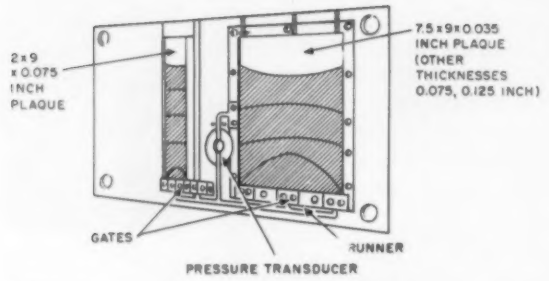

Figure 1. Instrumented Injection Mold

The value of K will vary according to the dimensions of the mold and the mold fill-out pattern. In some cases, this will be a rather complex relation. Often, however, flow through the mold can be analyzed in terms of simple configurations which have established flow resistance relations. The flow resistance factors for two common mold fill-out patterns are shown in the following.

(3) Rectangular fill-out pattern, such as that through an end-gated plaque mold:

$$K = \frac{12\,L}{W\,t^3}$$

(4) Tubular fill-out pattern such as that through the walls of a center gated dishpan or tumbler:

$$K = \frac{12\,L}{Cm\,t^3}$$

where L = mold cavity length, in.
W = mold cavity width in.
t = mold cavity thickness, in.
Cm = mean circumference, tubular type, in.

Experimental Equipment and Procedures

A special mold, shown in *Figure 1*, was used in these studies. The runner of the mold leading from the sprue to the individual cavities had provision for a strain gage pressure transducer, a Norwood type EP-10,000. This was calibrated by matching its output signals with known pressures obtained from a Baldwin Universal Tester.

The mold has cavities of equal length (9 inches) and thickness (.075 inch) and varying widths (2 and 7-¾ inches). The 7-¾ x 9 inch cavity has inserts of .035 and .125 inches thickness in addition to the .075 inch thickness. These combinations provide convenient tools for a systematic study of the effects of cavity dimensions on mold filling behavior. The mold also has provision for inserting various gates leading to the cavities.

Mold filling behavior was observed by recording pressure signals during flow through the mold on a fast responding Sanborn Model 60 recorder. A typical pressure-time curve during filling of the 2 x 9 x .075 inch cavity is shown in *Figure 2*. During the mold filling the pressure rises to maintain the constant volumetric filling rate against the increasing flow resistance in the mold.

Another procedure used to analyze mold filling was to measure pressures of a succession of short shots of increasing size until the mold had filled. As would be expected because of the constant filling rate, a plot of pressure vs. length of flow results in a curve very similar to that of the pressure-time recording. This can be seen by comparing *Figures 2 and 3*.

The materials used in these studies were low density and high density polyethylenes, with the major portion of the work being done with a .923 density, 23 melt index polyethylene.

TABLE 1—Pressure to Fill for Various Melt Indices

Melt Index (190°C, 44 psi) gms/10 min.	Pressure to Fill A 2 × 9 × .075 Inch Plaque psi
1.7	2,950
4.6	2,550
23	1,850

Effect of Mold Cavity Dimensions on Mold Filling. The fill-out patterns in the cavities of the special mold closely simulate a rectangular fill-out pattern. This is illustrated in *Figure 4*. Therefore, relation (3) may be used as the mold flow resistance factor for these cavities, and the mold filling relation becomes:

$$(5) \quad P = \frac{12\,L\,Q\,n}{Wt^3}$$

Under conditions of constant volumetric flow rate and constant effective resin viscosity, the pressure is expected to vary directly with cavity length, inversely with cavity width, and inversely with the cube of cavity thickness.

Effect of Cavity Length (Length of Flow). To test the relationship between length of flow and pressure, recordings of pressure were taken for various lengths of flow into the 2 x 9 x .075 inch mold cavity. Twenty three melt index, .923 density polyethylene was molded in an 8 oz. Reed-Prentice machine under conditions of 10 in³/sec. filling rate, 425°F material temperature, and 125°F mold temperature.

It was found that pressure increased directly with increasing length of flow—approximately 210 psi per inch of flow. The straight line relationship, shown in *Figure 5*, verifies the expected theoretical result that pressure is directly proportional to length of flow. Pressure to fill data for 1.7 and 4.6 melt index low density polyethylenes in addition to the 23 melt index resin are shown in *Table 1*.

The data in *Table 1* show the expected result, increasing melt index decreases pressure to fill. Increasing melt index decreases the slope of the pressure-length of flow curve and consequently reduces the overall pressure to fill. This is illustrated in *Figure 5*.

The major influence of length of flow on pressure clearly demonstrates the practical advantage of multiple gated

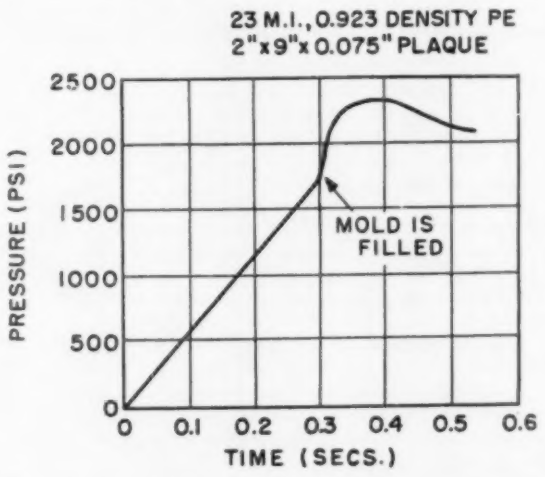

Figure 2. Typical Pressure—Time—Curve During Mold Filling.

TABLE 2—Pressure at Various Cavity Widths

Molding Conditions: 425°F material temperature, 125°F mold temperature, 10 in³/sec. filling rate.

Cavity Width (inches)	Pressure to Flow Material 5.25 inches (psi)
2.0	1,000
7.5	2,250

molds in reducing pressure to fill. For example, a mold could be designed where the addition of a second gate could reduce the flow length to fill by as much as 50%. This is illustrated in *Figure 7*. The reduction in length of flow will result in a marked decrease in pressure to fill the mold. However, it should be emphasized that the gates must be properly spaced so that they effectively reduce the length of flow. Otherwise, they result in only a minor decrease in pressure to fill.

Effect of Cavity Width and Cavity Thickness. If it were possible to study cavity width and cavity thickness under conditions of constant volumetric flow rate and constant effective resin viscosity, it is reasonable to expect that they would obey relation (5). That is, pressure would vary inversely with cavity width and inversely with the cube of the cavity thickness. However, the dependency of the viscosity of a polymer on the rate of shear makes it difficult to study these effects under conditions of constant effective resin viscosity. Generally, the viscosity of a polymer decreases as shear rate increases. For example, the approximate relation for low density polyethylene is as follows:

$$(6) \qquad n \propto \gamma^{-0.6}$$

where n = the effective resin viscosity, lb-sec/in²
γ = rate of shear in the mold cavity, sec.⁻¹

The relation for rate of shear for a rectangular mold fill-out pattern is:

$$(7)\ \text{Shear Rate, } \gamma = \frac{6Q}{t^2\ (W + t)}$$

Thus when cavity width or thickness is increased, two opposing mechanisms take place simultaneously: (1) Shear rate decreases causing effective resin viscosity to increase. This in turn tends to increase pressure requirements. (2) The mold flow resistance factor decreases according to $K = \frac{12\ L}{W\ t^2}$. This tends to decrease pressure requirements. Therefore, in the following analysis both of these effects must be considered when width or thickness is varied.

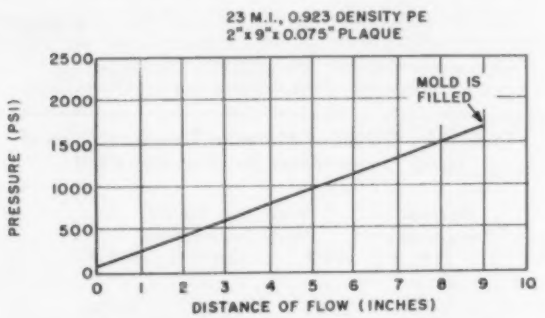

Figure 3. Typical Pressure—Distance of Flow Cure During Mold Filling.

TABLE 3—Pressure to Fill at Various Cavity Thicknesses

Cavity Thickness (inches)	Pressure to Fill (psi)
0.125	3,400
0.075	4,750
0.035	10,600

Cavity width was studied in the 2 x 9 x .075 inch and the 7.5 x 9 x .075 inch mold cavities with 23 melt index, .923 density polyethylene. The fill-out patterns of these molds differ slightly. As illustrated in *Figure 4* both cavities have semicircular fill-out patterns until flow reaches the sides of the cavities, then they assume rectangular fill-out patterns. However, in the 7.5 x 9 x .075 inch cavity the semi-circular pattern occurs for a much larger part of the filling—to 3.75 inches vs. 1.0 inch for the smaller cavity. Therefore, the analysis of cavity width can be made only between 3.75 and 9 inches of flow. The pressures, at the two widths, required to flow material that distance are shown in *Table* 2.

These data indicate that increasing cavity width increases pressure. Thus it appears that of the two opposing effects accompanying increase in cavity width—decreased mold

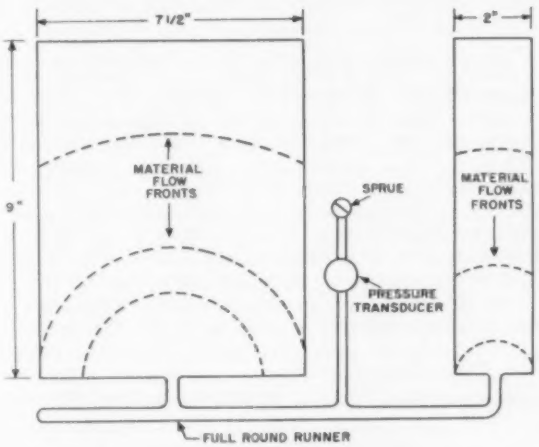

Figure 4. Cavity Fill-out Patterns

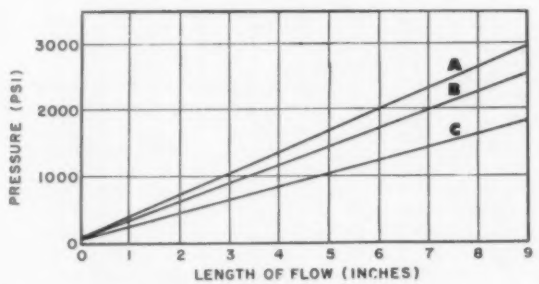

Figure 5. Effect of Melt Index on Pressure for Low Density Polyethylene.

curve	melt index
A	1.7
B	4.6
C	23.0

flow resistance and increased effective resin viscosity—the latter was predominant in this case.

Cavity thickness was studied in the 7.5 x 9 inch cavity in thicknesses of .035, .075, and .125 inch. Pressure to fill data at 10 in³/sec. filling rate, 425°F material temperature, and 125°F mold temperature are shown in *Table 3*.

The complete pressure length of flow curves for these determinations are shown on *Figure 6*. Decreasing cavity thickness from 0.125 to .075 inch resulted in a relatively minor increase in pressure to fill (1,350 psi). However, further decrease in cavity thickness to 0.035 inch produced a marked (5,850 psi) increase in pressure to fill. This, of course, demonstrates why thin-walled articles are so difficult to mold.

If the pressure required to flow from 3.75 to 9.0 inches in these cavities is plotted against cavity thickness on log-log coordinates the resulting curve approximates a straight line. The slope of this curve is −1.5. Thus, an approximate relationship between pressure and cavity thickness is obtained.

$$(8) \qquad P \propto \frac{1}{t^{1.5}}$$

Assuming constant effective resin viscosity in the mold filling relations for a rectangular fill-out pattern (5), one would predict that $P \propto \frac{1}{t^3}$. The difference between this relation and the experimental result must be due to the decrease in effective resin viscosity that accompanies the decrease in cavity thickness. This decrease in viscosity can come from two sources—increased rate of shear and frictional heat developed by the higher pressures.

Effect of Mold Fill-Out Pattern. The pressure fill-out curves for the 7.5 x 9 x .075 inch mold (*Figure 6*) illustrate the influence the mold fill-out pattern has on the pressure-length of flow relationship. It is recalled that the flow in the cavity to 3.75 inches has a semi-circular pattern and then assumes a rectangular pattern. During the semi-circular pattern the pressure varies exponentially with increasing length of flow. However, during the rectangular flow pattern pressure varies linearly with increasing length of flow, as predicted by the mold filling relation.

The effect of the mold fill-out pattern on pressure can also be seen in the fill-out curves of other molds. For example a center-gated rectangular dishpan mold has a circular fill-out pattern until its sides are reached, then the fill-out assumes a tubular pattern. The bottom of this mold is 7 x 9 inches and the height of the sides is about 5 inches. Wall thickness averages about 0.080 inches. As seen in the pressure-length of flow curve for the dishpan (*Figure 9*) the pressure increases exponentially with increasing length of flow during the circular flow pattern. During the tubular fill-out pattern, however, pressure increases directly with increasing length of flow. The latter result is predicted by the mold filling relation for a tubular fill-out pattern:

$$(9) \qquad P = \frac{12\,LQ\,n}{Cm\,t^3}$$

where Cm = the mean circumference of the mold, in. A tumbler mold (2 inch diameter base x 5 inches high) has mold fill-out patterns similar to those of the dishpan except that the tubular fill-out pattern is circular rather than rectangular in shape. Thus, the pressure—fill-out curve for this mold also shows an exponential relationship during the circular fill-out pattern and a linear relationship during the tubular fill-out pattern.

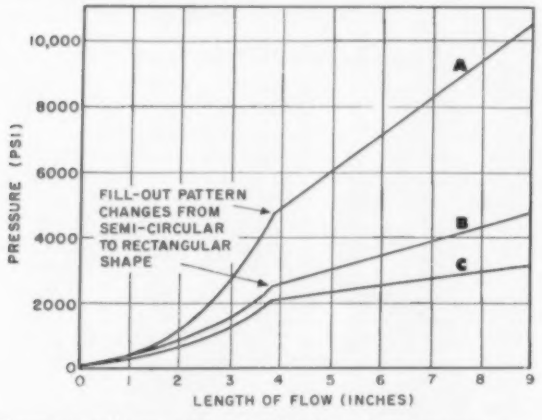

Figure 6. Effect of Cavity Thickness on Pressure.

curve	thickness (inches)
A	0.035
B	0.075
C	0.125

TABLE 4—Effect of Gate Size on Pressure to Fill

Molding Conditions: 425°F material temperature, 125°F mold temperature, 10 in³/sec. filling rate.

Cavity Thickness (inches)	Mold Gate	Pressure to Fill (psi)
0.075	No Restricted Gate	4,750
0.075	.040 × .230 × .020	6,140
0.125	No Restricted Gate	3,250
0.125	.040 × .230 × .020	4,700

Effect of Gate Size. Small gates (mold entrances) are often used in injection molds to minimize the surface blemish on the molded part where the sprue or runner is removed. The small gates introduce an additional pressure loss in the mold filling operation. The effect that gate size has on pressure to fill was studied by comparing pressure to fill data with a restricted tab gate 0.040 x 0.230 x 0.020 inch in dimensions with that obtained when no restricted gate was used. That is, the cavity itself formed the gate. The data, obtained in the 7.5 x 9 cavity in thicknesses of 0.075 and 0.125 inch are shown on *Table 4*.

The increase in pressure to fill resulting from the restricted gate was about the same for both cavity thicknesses, ranging from 1390 to 1450 psi. The magnitude of these pressures increases are surprisingly high. This suggests that the restricted gates should be avoided in molds difficult to fill unless they are absolutely necessary.

Effect of Molding Process Variables. In injection molding, the major process variables which influence flow behavior are material temperature, mold temperature, and volumetric filling rate. These variables were studied by molding 23 melt index, .923 density polyethylene in the 2 x 9 x .075 inch cavity over a broad range of conditions.

TABLE 5—Effect of Material Temperature and Mold Temperature on Pressure to Fill

Material Temperature °F	Pressure to Fill (psi) (Mold Temperatures) 80°F	110°F	140°F
400	2240	1940	1800
448	1730	1710	1700
485	1510	1510	1500

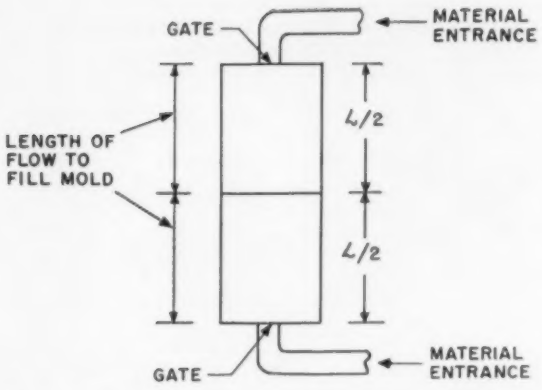

Figure 7. Effect of Multiple Gates on Length of Flow. Resin Flows Only Half as Far With Two Gates.

Material Temperature and Mold Temperature

Pressure to fill data at 10 in³/sec. for various material and mold temperatures are shown in *Table 5* below.

Note that increasing material temperature produces a more pronounced reduction in pressure to fill at the lower mold temperatures. Similarly, increasing mold temperature results in a more pronounced reduction in pressure at the low material temperature. It is quite apparent that these results are due to the effects increased material temperature and mold temperature have in reducing the cooling of the material as it flows into the mold. However, notice in *Table 5* that once the material temperature is increased above 400°F, changes in mold temperature have almost no influence on the pressure to fill. Thus at these conditions, the assumption made in deriving the mold filling relations that negligible cooling occurs during filling, is valid for low density polyethylene. If significant cooling had occurred, mold temperature would have had a more significant effect on pressure to fill.

Volumetric Filling Rate

Volumetric filling rate was studied in the 2 x 9 x .075 inch cavity in an 8 oz. IMPCO machine equipped with a special value to control injection plunger speed. Pressure to fill data at filling rates ranging from 4.5 to 18.5 in³/sec. are shown in *Table 6*.

As predicted by the mold filling relation, pressure increases as the volumetric filling rate increases. Note, however, that roughly a four-fold increase in filling rate (from 4.5 to 18.5 in³/sec.) results in less than a two-fold increase in pressure (from 1180 to 2120 psi). This data demonstrates the decrease in the viscosity of polyethylene as flow rate (or shear rate) increases. If the viscosity had not decreased during the increase in filling rate, the pressure to fill at 18.5 in³/sec. would have been 4,830 psi instead of 2,120 psi.

The shear dependency of the viscosity of polyethylene is even more clearly demonstrated by the following. The mold filling relation for a rectangular fill-out pattern may be used to calculate effective resin viscosity during flow through the 2 x 9 x .075 inch cavity as follows:

$$(10) \quad n = \frac{P\,(12)\,LQ}{Wt^3}$$

where pressure (P) and volumetric filling rate (Q) are determined experimentally, and L, W, and t are given by the dimensions of the cavity. A plot of effective resin viscosity, obtained in this manner, vs. rate of shear through the cavity is shown on log-log coordinates in *Figure 10*. The slope of the curve is −.62, indicating good agreement with general experience which states that the viscosity of polyethylene varies approximately as the − 0.6 power of the shear rate.

Viscosity Measurements of Several Polyethylenes

Using the procedure described in the previous section (relation 10) effective resin viscosities during molding were determined for several types of polyethylenes. The data are shown in *Table 7*.

The data for 0.92 density resins A and B illustrate the effect of molecular weight distribution on flow behavior. Resin A is a narrow molecular weight distribution material and resin B a broad molecular weight distribution material. Despite its lower melt index, resin B has a lower pressure to fill and a lower viscosity during molding than resin A. This indicates a difference in the viscosity-shear rate relationships of these materials.

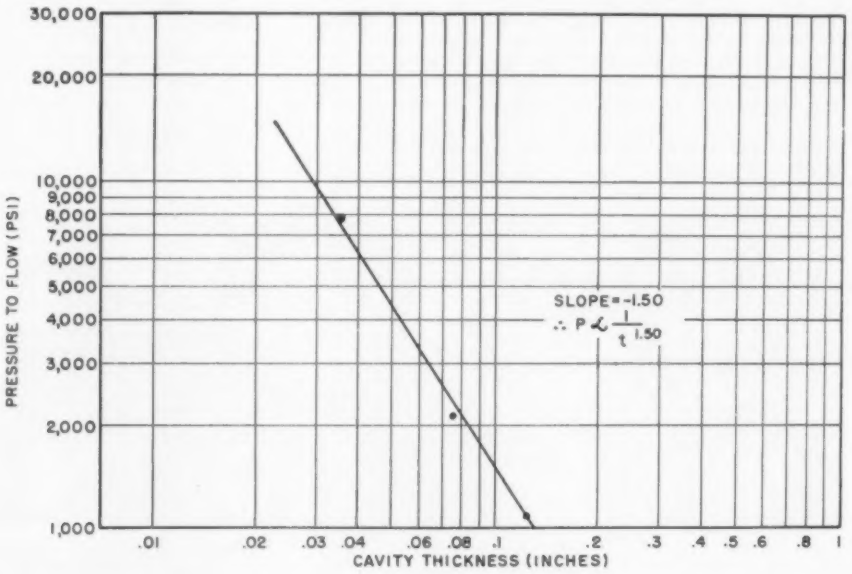

Figure 8. Effect of Cavity Thickness on Pressure in a Rectangular Fill-out Pattern.

TABLE 6—Effect of Filling Rate on Pressure to Fill

Molding Conditions: Material temperature 425°F, mold temperature 125°F.

Volumetric Filling Rate (in^3/sec.)	Pressure to Fill (psi)
4.5	1180
5.9	1300
9.6	1520
12.6	1745
18.5	2120

A comparison of the molding flow behavior of 0.92 density polyethylene and 0.95 density polyethylene is shown in the data for resins C and D. Even at essentially equal melt indices, the flow behavior of the 0.95 density material is considerably stiffer (more viscous) than the 0.92 density material. There are two possible explanations of these results: (1) The viscosity of the low density polyethylene might be more sensitive to increased rates of shear than the 0.95 density polyethylene and (2) because of the higher freezing range of the 0.95 density polyethylene it might be subject to a higher degree of freezing during mold filling than the low density resin. Both of these factors would contribute to the higher viscosity of the 0.95 density resin than the 0.92 density resin under molding conditions.

The data for resins D and E provide a comparison of the molding flow behavior of 0.95 and 0.96 density polyethylenes. Note that despite the higher (5.6) melt index of resin E its molding flow behavior is about equivalent to that of the 2.0 melt index, 0.95 density resin. Since these materials have reasonably similar freezing ranges, it appears that this result is caused primarily by differences in their viscosity-shear rate relationships.

Combining these results it is seen that based on comparing materials of equal melt index, as the density of polyethylene increases ease of mold fill-out decreases.

In conclusion, this study has shown that existing flow theory can be applied to provide a rather simplified analysis of the injection mold filling of polyethylene. The information provides a guide for the understanding and solution of mold filling problems and is particularly useful in the design of injection molds. Whereas the information developed still falls short of the ultimate goal of being able to predict the exact pressure required to fill various molds, it provides a guide for the understanding and solution of mold filling problems. In addition to this, the information developed concerning the effects of mold dimensions and fill-out patterns is particularly useful in the design of injection molds.

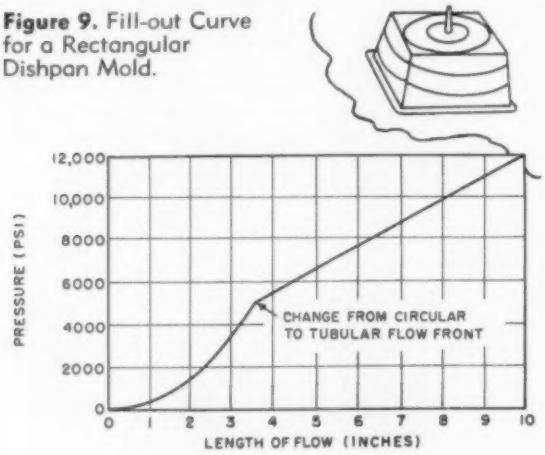

Figure 9. Fill-out Curve for a Rectangular Dishpan Mold.

TABLE 7—Effective Resin Viscosities of Various Polyethylenes

Resin	Density gms/cc	Melt Index	Pressure to Fill (psi)	Effective Resin Viscosity During Molding (lb.-sec./in^2)
A	.92	6.9	2,620	.00204
B	.92	4.6	2,500	.00195
C	.92	1.7	2,900	.00226
D	.95	2.0	3,580	.00278
E	.96	5.6	3,520	.00274

Molding Conditions: 425°F material temperature, 125°F mold temperature 10 in^3/sec. filling rate.

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2. Ballman, R. L., Shusman, T., and Shoor, H. L., "Flow of a Molten Polymer into a Cold Cavity", Industrial and Engineering Chemistry, Vol. 51, No. 7, July, 1959, p. 847-850.
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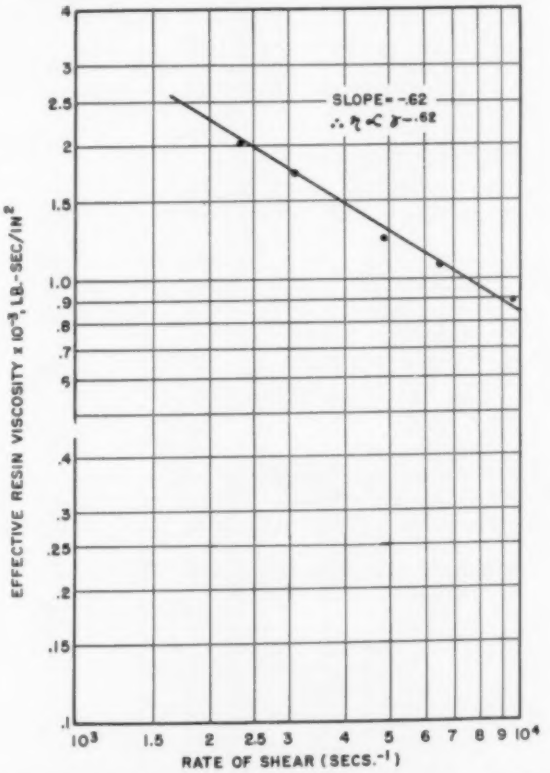
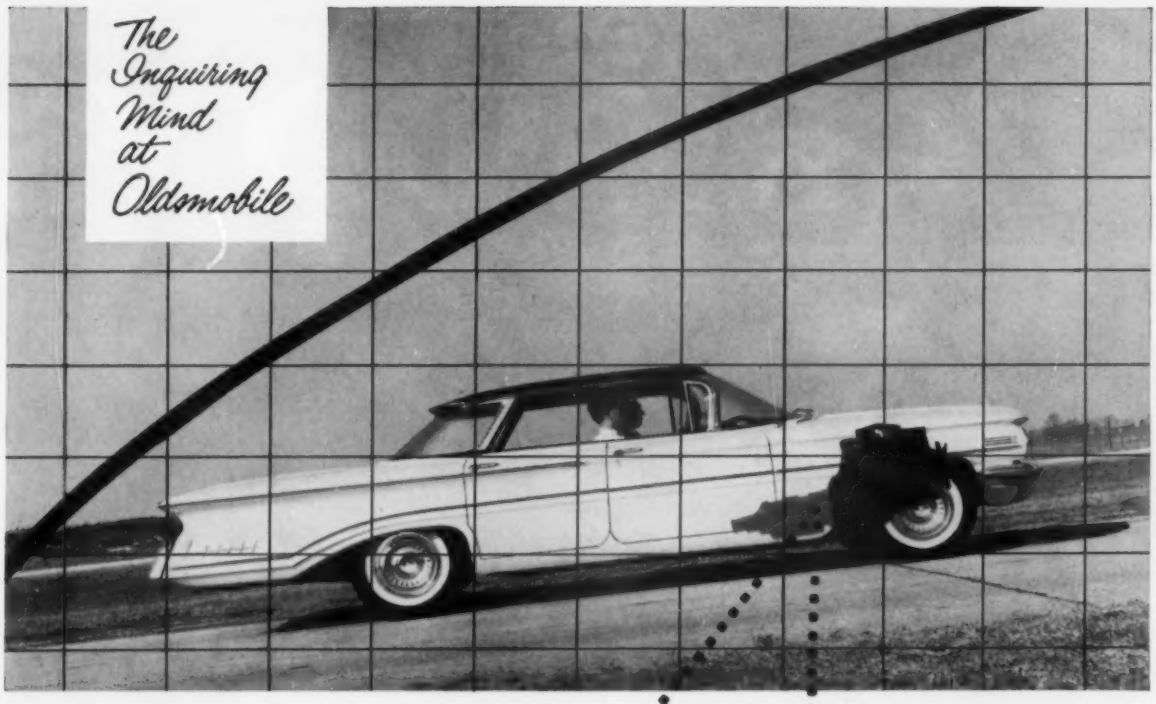


Figure 10. Effective Resin Viscosity-Shear Rate Relationship for 23 M. I. Low Density Polyethylene.

The Inquiring Mind at Oldsmobile



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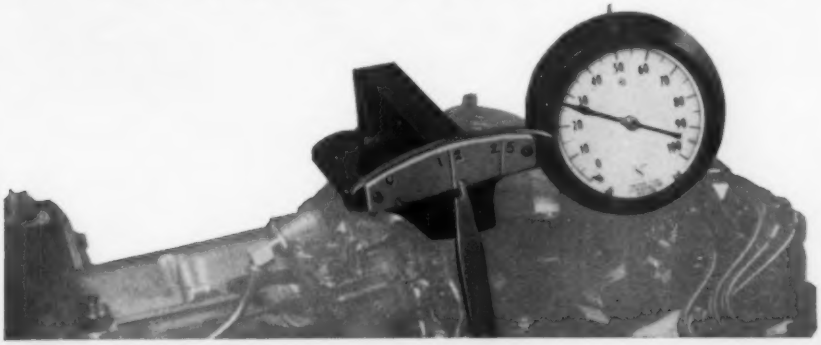

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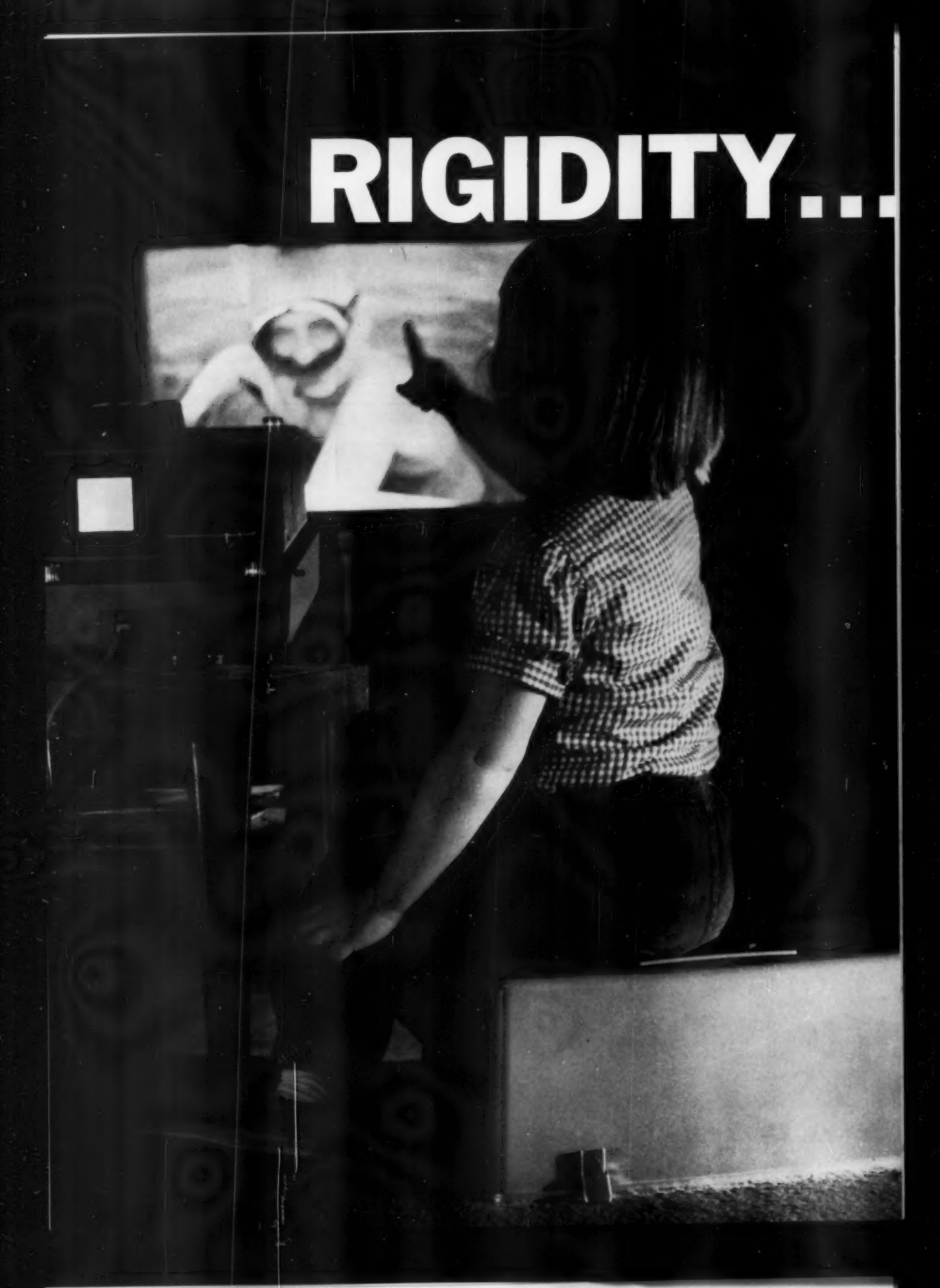
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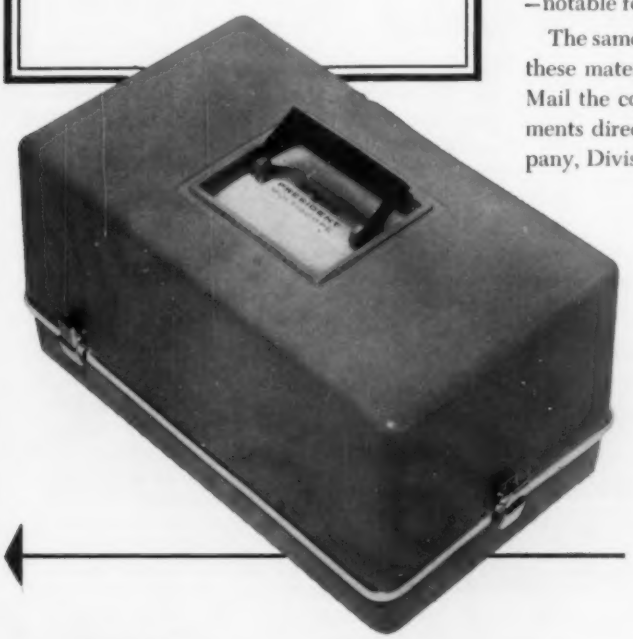

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SOCIETY ACTION

The Best of ANTEC

Frank W. Reinhart
Chairman
Editorial Advisory Board

With the number of fine papers, given at the 16th ANTEC, selection of only 7 posed difficult job

The seven articles chosen Best of ANTEC and published in this issue cover fields ranging from structural design with plastics to injection molding. It was not an easy job to select only seven. Selections were made by our Editorial Advisory Board, with the assistance of Jesse Day, Editor Emeritus, SPE Journal, and Melvyn Kohudic, SPE Journal Editor.

Decision of the Board was based on a number of factors: Value in its field, value to the profession, originality, and presentation. In addition, editorial balance—having a number of fields represented in the Best of ANTEC—further made the task of selection a difficult one. As Eugene C. Quear, Chairman of the Publications Committee for 1959 wrote describing last year's selections, "it is presumptuous to designate specific papers as being 'best'; however, it is desirable to set standards of technical quality to provide a guiding light for members of the Society to give incentive to authors for the improvement of technical papers presented at its meetings, and to reward those who have performed well." This statement summarizes perfectly the philosophy behind the Best of ANTEC.

1960 MEMBERSHIP GOALS

As announced in the February issue, one of the major goals of SPE President George W. Martin's administration is a membership of 9,000 by February 1, 1961. To attain this, the Society must receive 1800 new membership applications by that date and the Membership Committee, under the guidance of Chairman Sherman M. Crawford, has set this figure as the objective of their 1960 drive.

This Committee, also, recently announced that the 1960 Membership Contest will start on April 1 and continue through December 31. Rules will be the same as in 1959 with the championship banner being awarded to that Section showing the greatest percentage increase in membership over the nine-month period.

edited by **Thomas A. Bissell**
SPE Executive Secretary

Plastics in Buildings PAG'S 1960 Programs

PAG Progress

Armand G. Winfield,
Chairman, Plastics in Buildings PAG

Traveling Exhibit Features Plastics in Buildings

The Professional Activity Group —Plastics in Buildings has chosen to undertake an extensive and ambitious program for 1960. This program can be divided basically into three main projects:

1. The completion and ultimate publication of a directory of plastics terminology.

Purpose of this project is to satisfy the demands of architects and builders for a common denominator on which all professions involved in the building field may have a common means of communication.

Dr. Frank Reinhart (National Bureau of Standards), Chairman of this project, began his work in February 1959. He and his committee estimate that a first draft will be completed by Summer, 1960.

With the growing interest in the potentials of plastics in buildings, Dr. Reinhart's efforts will be an important step in improving relations through clear communication with our fellow craftsmen and professional colleagues.

2. A traveling educational exhibit.

Originally the 1958-1959 PAG had chosen as one of three projects, a study to provide reference sources on the "state of the art" by surveying current literature, abstracting pertinent articles and assembling available data on specific related subjects. All of this information was to be disseminated among the joint professions.

The writer who was appointed Chairman of this project, suggested a device to combine all phases of the project and to disseminate the information visually and tangibly instead of by customary means. The proposal was the preparation of a traveling exhibition combining all phases of plastics in buildings. This would be circulated to museums, art institutions and universities in important cities throughout North America on a self-sustaining, self-liquidating basis. The exhibit in each location would last about a month.

The visual combination of various examples of plastics in buildings as they actually applied to the art would provide a healthy impact heretofore not exploited in the PAG Program.

Basically, the plan is to get the support of groups of exhibitors representing various phases of the plastics in buildings fields. These exhibitors would underwrite the cost of the display.

The exhibition would be designed professionally as an integral unit and constructed on a high technical, educational, plane—not as a traveling commercial. It would be directed toward the professional architect, contractor, builder, interior designer and students of these professions—not necessarily to capture the fancy of Mrs. Housewife.

The exhibit would then travel to museums or universities in each of some 16 cities and would only cost the exhibiting institution a nominal fee to be used to defray the freight from the last exhibition point.

In addition to the exhibit itself, a souvenir catalogue would be prepared giving listings of exhibitors and sources of available plastics materials. There would also be feature stories concerning plastics in the various phases of buildings—from the architectural point of view—the interior decorator's viewpoint, and so forth. The book would also contain specification sheets on the materials in the exhibit.

A Message from Frank W. Reynolds, Administrator, Professional Activity Groups

There are to date, fourteen Professional Activities Groups which were given official sanction by action of Council. This was the result of a voluntary request by members of SPE who had an earnest desire to promote their knowledge of different fields to the plastics industry for the benefit of the Society and its members.

Council's approval of these Groups, lent credence to the implied, if not expressly stated recognition that they are the official engineering and scientific voice of the Society.

Further evidence of this recognition is the proposed reorganization of the Society by establishing an Engineering Board for ruling on all policies and matters related to plastics engineering which will be composed predominately of members from Professional Activities Groups.

One of the most effective ways for promoting the position of PAG's is through publicity in the Journal. Consequently, a feature will be included in each issue on a continuing basis and will be entitled PAG Progress.

The report by the Plastics In Buildings PAG appearing on this page is the initial feature article.

The plan includes tying in SPE Sections the country over into the PAG Exhibit. Let us assume, for example, that the traveling show—which will be called, "Plastics—A New Dimension in Buildings"—is planned for St. Louis appearance. The St. Louis Section would be alerted in advance of the opening.

Members of this Section most concerned with the various building fields—and especially St. Louis Section members who are also members of our PAG—or corresponding PAC's—would take the initiative in coordinating the effort on behalf of the display and its relationship to local industry. They would solicit cooperation from the local press; they would seek the cooperation of the exhibiting institution in preparing publicity for the exhibit. An opening might be arranged as a special affair the night prior to public viewing. This opening would be an invitation affair for town celebrities, educators, architects, contractors, builders, decorators, etc., and the SPE section would be the host. Likewise, Section members most directly concerned with plastics building projects might arrange special tours on an individual basis for associates and colleagues during the display period.

Some Sections might find it profitable to plan their monthly meeting (which would coincide with the exhibit) around the general subject of one or more phases of plastics and building. Special speakers might attract architects and builders to this meeting which could be publicized as an open one.

The initial plan for the exhibit was approved by SPE Council on October 26, 1959 after many months of negotiation, and after checking with our affiliated professional societies to make sure that there was no duplication or overlap of their activities.

A General Policy Board was then formed to formulate the necessary steps and procedures that would reflect the best interests both of SPE and of industry as a whole. This policy board consists of the officers of our PAG—Plastics in Buildings:

Armand G. Winfield, Chairman (DeBell & Richardson, Inc.)

Dr. Mortimer H. Nickerson, Vice-Chairman (Arthur D. Little, Inc.)

Robert W. Sherman, Secretary (Union Carbide Plastics Company)

These ex-officio members:

George W. Martin, SPE President (Holyoke Plastics Corp.)

Frank W. Reynolds, PAG Administrator and SPE's First Vice President (International Business Machines Corporation)

Thomas A. Bissell, SPE's Executive Secretary

And these specialists:

Harold Horowitz, Registered Architect

Henry M. Richardson, Plastics Consultant, (DeBell & Richardson, Inc.)

Frederick B. Robinson, Director, (Springfield Museum of Fine Arts)

In addition to this General Policy Board, invitations are being currently extended to prominent persons to serve on a General Advisory Subcommittee. These members will be announced subsequently.

The tentative schedule is to open the exhibit at the Springfield, Mass. Fine Arts Museum late in 1960, and if possible, have it in Washington D.C. during the 17th ANTEC. From there it will be scheduled on a tour of an additional 14 cities. The display will be up for one month at a location and two weeks for breakdown, traveling, and set-up between exhibits.

3. Panel Session at ANTEC—

Henry A. Perry, Chairman of the Speakers' Committee for the 17th ANTEC has asked each PAG administrator to suggest a possible program or session subject that might be included among the subjects to be assigned for the Washington, D.C. meetings. This PAG has already applied for permission to arrange a special panel session in conjunction with the traveling exhibit on Plastics in Buildings which should be in Washington simultaneously with the 17th ANTEC.

Our Plastics in Buildings PAG feels a heavy responsibility not only to its own participating members who have chosen to undertake this ambitious program, but also to SPE which has shown its faith by underwriting our program; to the associated industries whose paths it will cross along the way.

We in our PAG are making every effort to help shape the trend of a greater and more intelligent use of plastics in more and more building applications. We cannot make or execute these plans alone. We need the help and support of all SPE members and friends and we would welcome your ideas and inspirations. We invite your participation in our PAG—Plastics in Buildings as we move along toward our goals in this banner year.

—— ■ ——

edited by
Frank W. Reynolds,
PAG Administrator
(International Business Machines Corp.)

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France

INDUSTRIE DES PLASTIQUES MODERNES

NOVEMBER, 1959

Pressure Molding of Plastics and Rubber—page 2

The author relates the step by step procedure in the preparation of molds for injection machines by the use of Devcon C. A detailed description covers all steps from the preparation and mounting of the prototype through the casting of the cavity and the male part of the mold to its final assembly.

Glass Reinforced Polyesters

A series of tests for mechanical stability was conducted on laminates prepared from glass mat and unsaturated polyesters as well as polyesters containing 20% fillers of calcium carbonate. The results of immersion tests in sweet and salt water as well as the results of exposure to atmospheric conditions are discussed and conclusions are drawn as to the suitability of such materials for certain types of work.

PLASTIQUES BATIMENT

DECEMBER, 1959

Plastics in the Fight Against Fire

Various categories of slow-burning, fire-retardant and self-extinguishing plastics are given, together with the most common methods to render plastic building materials inflammable. A number of plastics being used in buildings are listed as examples where they may replace advantageously the more traditional materials.

Encapsulation and Impregnation of Electrical Components

Data are presented on the dielectric constants of expanded polystyrene and on the loss constants and thermal conductivity of various polyurethanes as a function of their various densities. In addition, the most common electrical properties of various plastics are given, such as polystyrene, phenol-formaldehydes, polyesters, glycols, nylon, silicones and fluorinated resins.

PLASTICS AROUND THE WORLD

This month's column has been made possible through the contributions of these abstracters:
Leonard S. Buchoff (Materials in Design Engineering)
Alfred Rexer (Plastics)
R. George Hochschild (Plastiques Batiment)
Hans Mayer (Industrie Des Plastiques Modernes)

Great Britain

PLASTICS

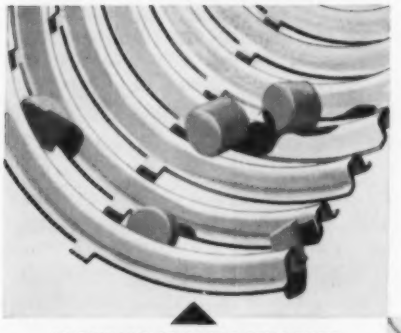
DECEMBER, 1959

Multi-Head Extrusion Unit—pp 489-90

The problem of increasing the output and efficiency of an extruder when producing small dimension

(*Continued on page 442*)

get accurate sizing with SIMON-CARTER machines



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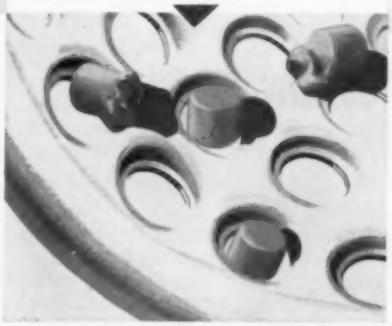

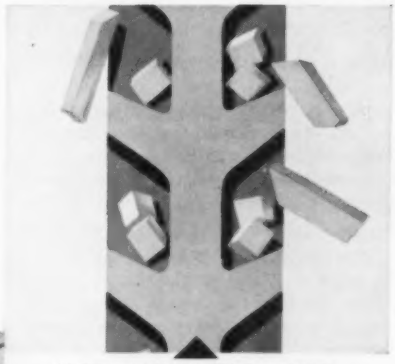

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PLASTICS AROUND THE WORLD

products is claimed to be overcome by a new multiple-head unit developed by Oerlikon Plastik AG., Stans/NW. Switzerland.

Structure and Formation of Plastisol—pp 28-30

A technical treatise of plastisols covers steric considerations, fusing temperatures and viscosities, agglomeration effects, and oxonium systems.

Temperature Control in Plastic Testing—P. N. Bestelink, R. Millwood & C. E. Stephenson

This article describes a device which was developed to give either of the heating rates required by the Vicat Softening Point and the Heat Distortion Tests automatically. Pictures and charts are included.

The Applications of Epoxy Resins in the Electrical Industry—pp 505-509

A comprehensive review gives the applications of epoxy resins in electrical engineering industry and indicates lines on which developments are taking place. References are given.

Cross-Linking of P.V.C. By Ionizing Radiation—S. H. Pinner, pp. 35-39

Polyvinyl chloride can be cross-linked by the direct action of radiation, but the relatively high doses required render the process uneconomical. Irradiation in the presence of diallyl or triallyl esters leads to highly cross-linked rigid products. The physical properties of such products are described.

The Weathering of High Polymers—H. J. M. Langshaw, pp. 40-45

A comprehensive article outlines in broad detail the factors responsible for deterioration in normal service of all high polymers. 108 references.

United States

MATERIALS IN DESIGN ENGINEERING

DECEMBER, 1959

Oriented Thermoplastic Sheet and Film

Orientation increases mechanical strength and toughness in thermoplastics, such as polystyrenes, acrylics, polyesters, sarans and polyethylenes. Orientation lines the molecular chains in a predetermined direction. Design considerations and limitations are discussed.

Materials for Gaskets, Packing, and Seals

Advantages and disadvantages of the various plastics and elastomers used in gaskets and seals are presented. Teflon, filled and unfilled, will perform in a variety of extremely difficult applications, where other materials would be impossible or short-lived.

JANUARY, 1960

How to Specify Molded Plastic Parts

This excellent article describes the method of plastic, design and performance specifications. There is a discussion of dimensional tolerance and final testing that would help novices and those experienced in the field.

Silicone Rubbers that Cure at Room Temperature

A series of RVT (room temperature vulcanizing) silicone rubbers are being used that have excellent heat resistance and negligible shrinkage during cure. They are used for sealing aircraft parts, encapsulating electrical coils and other components, and in the production of flexible short run casting molds.

ABOUT MEMBERS

Ernest Munkacsy joins UBS Chemical Co. as salesman in the Central Midwestern territory. He was previously associated with Moor and Munger, Inc.

Ronald P. Marsh has joined Mobay Chemical Co. as a technical service representative for polycarbonate resins.

Henry C. Guhl has been elected vice president for engineering, National Vulcanized Fibre Co. Mr. Guhl joined National in 1954 as manager of quality control and process engineering. He was named engineering manager in 1955.

C. S. Shoemaker will head up a new sales office in Greensboro, N. C. for Union Carbide Plastics Co. Mr. Shoemaker is a chemical engineering graduate of Ohio State University, 1948.

Wilbur J. Bergeron joins Selas Corporation of America, Dresher, Pa. as sales representative in the Houston sales district. He was formerly sales engineer for Sterling Packing and Gasket Co., Houston.

Robert Shevett has been appointed Technical Sales Director of the Rainville Co., Inc. He is a graduate of Stevens Institute of Technology in Hoboken, N. J.

William A. Hanan attended the President's Conference on Occupational Safety, held in Washington D. C., March 1-3, 1960. Mr. Hanan's interest and knowledge is in the use and handling of toxic pigments and solvent vapors used in the formulating, compounding and end use of plastics and organic coatings.

W. J. Smith has been named manager of Firestone's new synthetic fiber plant, Hopewell, Va. He is a native of Paterson, N. J. and was graduated from Rutgers with a B.S. in Chemistry, 1944.

Leslie J. Kovack, formerly president of Boston Plastic, will become vice president of Modern Plastic Machinery Corp. He will be in charge of the blow molding division. Boston Plastic Machinery Inc. was a manufacturer of plastic blow molding equipment.

Frank Connell joins Delaware Barrel & Drum Co., Inc., Wilmington, Del. He was formerly associated with Grace Chemical Co. of Clifton, N. J.

Carl L. Ackerman, formerly chief Mechanical Engineer for C. G. Conn Co., Elkhart, Ind. has been appointed Chief Mechanical Engineer for the Baldwin Piano Co., Cincinnati, Ohio.

Raymond H. Marks, formerly Vice President in charge of Sales for Cary Chemicals Inc., has been appointed Executive Vice President. His new duties will include the coordination of all manufacturing, research, and sales activities.

L. E. Welch, Glen Ridge, N. Y. has been appointed Manager of Procurement for Pitt-Consol Chemical Co., Newark, N. J. Mr. Welch joined Pitt-Consol Chemical Co. in 1956 and, most recently, was manager of the company's phenolic molding powder operation.

Herbert R. Clark has been transferred from Technical Representative, Philadelphia, to Technical Service Specialist, Technical Service Dept., Bound Brook, N. J., for Union Carbide Plastics Co. Also for Union Carbide Plastics, **Richard G. Hess** was assigned to the Rochester, N. Y. office where he will handle flexible packaging, bonding and laminating sales.

William A. Kelley, former technical service representative with Monsanto Chemical Co. plastics division, has joined Frank W. Egan & Co. as a sales engineer.

Alan J. Breslau has been appointed Technical Director of Mitchell Specialty Division of Industrial Enterprises, Inc. Mr. Breslau was in charge of urethane foams and epoxy resins with the Thiokol Chemical Corp. He has a Master's Degree in Chemical Engineering from Columbia University.

Carter P. Schriber has been made Sales Manager of the Textile Division, Coast Manufacturing & Supply Co.

Julius Palen, a past president of the Golden Gate Section was the guest speaker at the Purchasing Agents Association of Oakland, Calif. His subject was "Plastics, an Industry for Service."

A. F. Thomas was appointed to the newly created position of sales manager for The Goodyear Tire & Rubber Co., Films & Flooring Div.

Bill McConnell, formerly Vice President of Air Accessories, Inc. is now General Sales Manager of Texstar Plastics. The plastics division of the Texstar Corp. was formed through a merger of Air Accessories and Texstar Corp.

Harry A. Kahn

Harry A. Kahn and **Robert H. Steiner** have been appointed associate directors of research and development, The Kordite Co., a Division of National Distillers and Chemical Corp.

Robert H. Steiner

SECTION NEWS

SPE Officers Visit Sections

At a meeting in Holyoke, Mass., February 3, 1960, President George W. Martin, First Vice President Frank Reynolds, and Executive Secretary T. A. Bissell completed the 1960 schedule of Officers Section travel. The schedule calls for a visit by an SPE Officer to every one of the 44 Sections, with the possible exception of Osaka, Japan.

Visits to Eastern New England and New York Sections RETECs (Regional Technical Conferences) have already been arranged. Messrs. Martin, Reynolds, and Bissell will visit Eastern New England September 8 and 9, and on October 19, Messrs. Martin, Fred C. Sutro, and Bissell will travel to the New York Section.

Toledo

Blown Containers

R. E. DUNHAM

After the installation of the president for 1960, Ron Wagner, by outgoing president Jim Hyland, on January 20, 1960, the Toledo Section enjoyed a talk by W. J. Graham, Sales Manager for Blown Plastic Containers, of the Owens-Illinois Glass Company on "Blown Plastic Containers". An interesting questioning period followed.

Mr. Graham discussed the reasons for Owens-Illinois entering into blown plastic containers which compete with existing glass containers made by Owens-Illinois. He pointed out that low density polyethylene bottles do not compete with glass price-wise while high density polyethylene containers can. Some reasons why the high density bottle is desirable in relation to glass are less weight to lower shipping costs, unlimited color, durability (non-break) and better tactile properties. Disadvantages are lack of clarity and limited chemical resistance.

In comparison with a can, the plastic bottles have one-fourth the weight, advantage of shape and design and price below coated tin-plate. Some limitations in plastic containers now being made from high denstiy polyethylene are: contents developing pressure cannot be packed, permeation to gases and solvents, slight odor for delicate products, and hot fill cannot be used.

Baltimore-Washington

New Officers Elected

STANLEY PROSEN

The February meeting was called to order by Section President Robert Stromberg. It was attended by 40 members and guests.

Dr. Albert Lightbody, National Councilman, reported on National SPE happenings.

The speakers of the evening were Paul Kemper of du Pont, William F. Christopher of General Electric, and George Taylor of Hercules, who presented talks on Delrin, Lexan, and Penton, respectively. The properties and uses of each material were discussed. All three materials, it turned out, have excellent dimensional stability, are creep resistant, and have high heat distortion points. Stressed in the talks, in addition, were the excellent frictional properties, outdoor weatherability, and metallic-like properties of Delrin, Lexan's toughness with high impact and ductility, and Penton's negligible water absorption and anti-corrosion properties. Molding hints and uses were also discussed.

The following Officers were elected for 1960:

President: Robert R. Stromberg, National Bureau of Standards
Vice President: Taylor A. Birckhead, Birckhead Corp.
Secretary: Walter R. Chance, Chance and Associates
Treasurer: T. Milton Oler, Jr., The Martin Co.

Elected to Board of Directors (3 years); Myron DeFries, Atlantic Research Corp., Casmir Plasewicz, Westinghouse Air Arm Div., and Stanley P. Prosen, U.S. Naval Ordnance Lab.

Cleveland

Largest Molding Operation Discussed

EDWIN K. McCLELLAN

At the February 15, 1960, meeting of the SPE Cleveland Section, 81 members and guests were present at the Cleveland Engineering Society building to hear Mr. Frank Adair, Senior Engineer of Western Electric's Indianapolis plant, discuss "The World's Largest Molding Operation". This plant at present has 109 machines and will have 170 by 1962. Mr. Adair showed samples of the approximately seven million telephones which Western Electric will mold this year. He also remarked on his company's interest in automatic molding and hot runner molds and discussed problems in maintenance and service to their machines.

Central Indiana

Polyester Resins for Corrosion Resistant Applications

D. E. COLLINS

The February meeting of the Central Indiana Section was held at the Continental Hotel, Indianapolis. In attendance was Mr. Don Eills, National Committee member. He presented advantages of being a member of S.P.E. and encouraged increased membership.

Mr. Al Torres of Atlas Powder Company presented a technical paper on "Polyester Resins for Corrosion Resistant Applications." His company has been developing a corrosion resistant material and compiling data over a period of three months. This material known as "Atlac 382" was compared 1/16 inch thick to general purpose and isophthalic as to the effects from acids, distilled water, electrosol, caustic and clorox. The study is to be continued for one year. Some of the applications were shown as large rubber lined containers replaced by this polyester.

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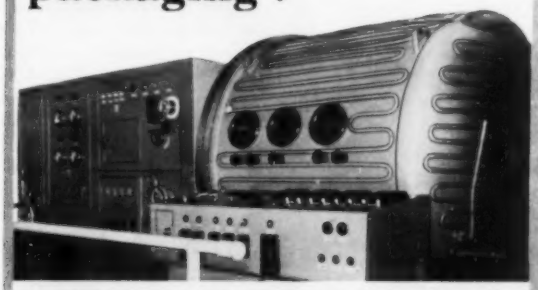

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Buffalo

Instrumentation Discussed

ANDREW HAMMERL

On the evening of February 8th Mr. Conrad Claeson, Director of Training for the Wheelco Instrument Division of Barber Coleman, Rockford, Illinois, spoke on "Instrumentation in the Plastics Industry".

Mr. Claeson explained the basic principles of switching, as applied to heating controls, and process requirements for various types of temperature adjusting devices. Following this introduction he described their Saturable Core Reactors designed to adjust temperatures more efficiently than the rheostat type of control.

Discussion followed on methods of application of these Reactors and the advantages that can be gained by their use.

Newark Section

Decorating Plastics and the Dusseldorf Fair

B. W. WALKER

The February meeting was attended by about 150 members and guests. A report was presented by the PAG on Extrusion, which announced a series of lectures to be given this Spring. At the first one, scheduled for March 21st, Dr. Bryce Maxwell of Princeton discussed new principles of extrusion. The Education Committee marked the fifth anniversary of the Plastics Engineering Course we have been sponsoring in cooperation with the Newark College of Engineering. This course has grown steadily in quality, scope, and interest. A new plastics laboratory is being planned for the college.

The technical program began with a talk on "Decorating of Plastics Products" by Mr. Arthur N. Skeels, president of Art Decorating Company. He presented an interesting and informative discussion of the procedures, such as hot stamping, silk screening, spray painting, and offset printing, used in decorating plastics. He described the problems presented by the increasing number of types of plastics and types of applications. The most important single suggestion he made was that the coloring materials used, whether ink, paint, leaf, or pigment, be especially compounded for the particular plastic being decorated.

Dr. Ernest C. Bernhardt of E. I. DuPont de Nemours and Co., Inc., discussed "The Dusseldorf Fair, New European Machine Developments". Ernie gave an extremely interesting and provocative account of his personal observations, including equipment which he found of particular interest. One interesting process was an extrusion set-up for the biaxial orientation of thermoplastic pipe. Linear polyethylene pipe, made by this process, shows greatly increased strength and reduced tendency to cracking. Also noteworthy was the extent to which European manufacturers are using combinations of screw and ram feeds for injection molding machines. Some spirited discussion ensued, in which it was pointed out that requirements for making a machine "commercial" may be somewhat different here and abroad.

Southern California

New Trends in Thermosetting Materials

IRWIN M. ZELMAN

At its February 4th meeting, some 130 members and guests of the Southern California Section heard a panel discussion on "New Trends in Thermosetting Materials." The panel moderator was Lloyd Dixon, Hysol of California, whose opening remarks set the theme for the discussion.

Rod Maybee, Shell Chemical Co., covered the new developments in epoxy resins. Mr. Maybee stated that preimpregnation is becoming more and more important, and when coupled with the impregnation of glass roving for filament winding, has opened important new fields for reinforced structural plastics. He also discussed the use of epoxies in concrete coatings and the limiting factors in the development and use of epoxy resins. A mention was made of the products and techniques that have been developed to overcome these limiting factors.

The next panel member was Burt Prince, Specialty Resins, whose talk covered the new trends and uses in polyesters. Mr. Prince gave a brief history of polyester resin development and a resume of the different manufacturing techniques that are used in manufacture of polyester parts. Mr. Prince concluded with a discussion of new resin developments and resin producing equipment.

Red Baurmeister, General Electric Co., was the third panel member, covering the new trends in silicones. He gave a brief review of the various silicone compounds from "Nutty Putty" to lubricants. A more detailed survey was made of the silicone rubbers, with particular attention to the R.T.V. compounds. Several new and unusual applications were highlighted with suggestions for uses in conventional applications.

The last panel speaker, Mr. Felix Karas of Messa Plastics, gave a brief history of the development of the diallyl phthalates. Their structural and electrical properties were compared to those of other plastics and the importance of flame proofed diallyl orthophthalate and diallyl metaphthalate was emphasized by reference to several military applications and to Underwriters Laboratory approval.

Connecticut

Blow Molding Night

K. G. CLARKE

The new field of blow molding was featured at the February 12th meeting of the Connecticut Chapter of the Society of Plastics Engineers, held at the American Brass Country Club in Naugatuck.

Mr. Lee J. Zukor, Engineering Editor, Plastics Technology, spoke about the many different types of techniques and equipment used to produce blow molded items. These methods generally fall into four categories: (1) parison injection, (2) parison extrusion, (3) closed tube injection, and (4) sheeting. Although the techniques vary, the principles involved are the same throughout. Mr. Zukor used movies, slides, and samples to illustrate the equipment, its operation, and the many applications pointing out the diversity of product obtainable by this new technology.

The Chapter was honored to have as guests several representatives of the blow molding equipment manufacturers. Among them were Mrs. I. E. Ledermann, Kautex—U.S. Sales Company, Inc., Flushing, New York; Burton Lilling, Barclay Industries, Inc., New York; Tom Ryan and Soren Grae of the Rainville Company, Bridgeport, Connecticut, and W. A. Shilling of Auto-Blow Corporation, Bridgeport. In discussions following Mr. Zukor's presentation, these representatives emphasized the enormous size of the markets open to this technique, and the importance of selecting a properly designed machine for each type of job to be produced.

Rochester

Plastics in Construction

DAVID L. MESSENGER

The regular monthly meeting of the Rochester Section was held at the Colonial Hotel on February 8, 1960.

As a token of appreciation for the most excellent job done during his term of office, past president Mr. P. T. Schurman of Union Carbide Plastics, was presented with a gavel.

Speaker of the evening was Mr. Charles S. Cheston, Jr. of Monsanto Chemical Company, Springfield, Mass. who spoke on the use of Plastics in construction. His very interesting talk was complemented by a film on Monsanto's "House of the Future", now located at Disneyland in California.

The meeting was attended by 32 members.

Milwaukee Section

Plastics in Packaging

C. H. STRONG

Guest speaker was Dr. F. J. Gilbert, Laboratory Manager, Milprint, Inc. His subject was "Use of Plastics in the Flexible Packaging Industry."

The talk consisted of the history and development of flexible packaging in the plastics field, followed by the problems of today as to what requirements are needed for a package to do, then listing the importance of research and development for the future markets. He concluded in what to expect in the future with new types of resins being developed.

(*Continued on page 449*)

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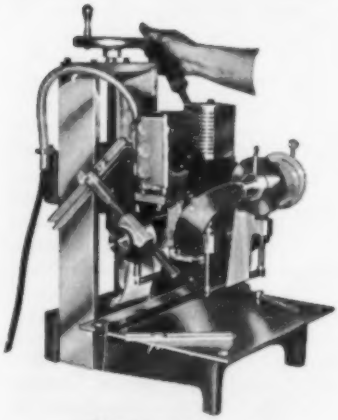

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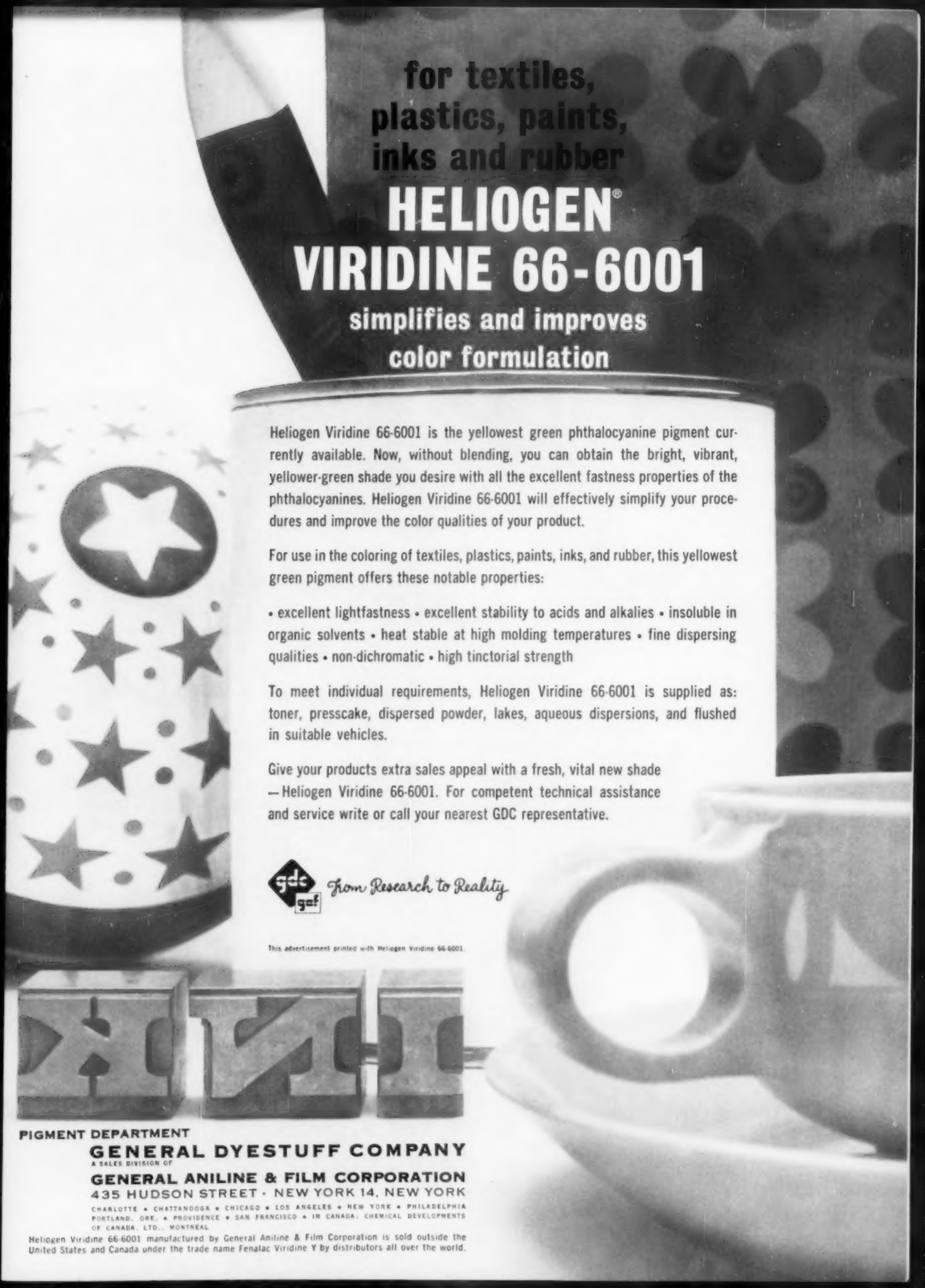

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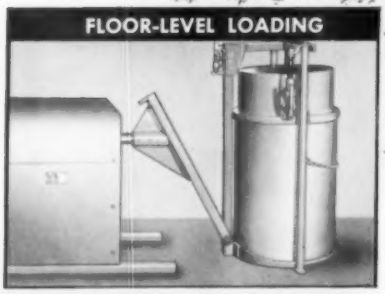

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Write for Bulletin DM-290

17G-3

SECTION NEWS

(Continued from page 446)

Akron

High Density Polyethylene

GEORGE REESMAN

Mr. Gordon Buehrig of the Ford Motor Co. presented a very interesting talk entitled *"1960 Ford Side Shields Made of High Density Polyethylene—A Case History"* before the Akron Section on Monday evening, February 22. Slides were used to show the complex structure of the unusual mold design.

The side shield is the curved piece which fits around the bottom of the seat. It is subjected to scuffing and impact from the passenger's feet as they enter and leave the vehicle. The high density polyethylene replaced a steel part at 2/3 the cost of steel. In addition it had styling advantages, lighter weight, increased scuff resistance, greater denting resistance and color could be incorporated directly into the material.

The first parts produced were badly warped, but changes in gate design and mold cooling resulted in production parts entirely free of warp.

St. Louis

St. Louis Committee Chairman Selected

RICHARD H. KOEHRMANN

The February meeting of the St. Louis Section of the Society of Plastics Engineers was held at the Clayton Elks Club on February 15, 1960. Fifty-one members and guests were present.

The new committee chairmen for 1960 are:

B. M. Coons—Program Committee
A. F. Therrien—Membership Committee
D. E. Otto—Credentials Committee
R. F. Ostman—House Committee
R. H. Koehrmann—Publicity Committee and S.P.E. Journal Recorder

The March meeting was a talk on "Tooling for Plastics" by Mr. Gordon Thayer and the April meeting, Mr. John Young, will cover "Applications of Plastics in the Automatic Industry."

President Dean reported on three group European travel plans available to SPE members and their families for reduced rates. The section was formally invited by a representative of of ASTME to attend their series of seminars on "Plastic Tooling" to be held February 24-25-26, 1960 at the Chase Park Plaza Hotel in St. Louis.

The speaker for the evening was Mr. Thomas W. Mullen of the Celanese Plastics Company. His subject was blow molding. Mr. Mullen discussed current commercial equipment for blow molding, applications, molds, the patent story, and general economics of the industry. The talk was followed by an active question and answer session which lasted for 30 minutes.

Pioneer Valley Section

Plastics vs. Die Casting

ROGER JOHNSTON

On 11 February, 1960, Bill Bracken of the Hercules Powder Co. treated the group to a fine discussion of the economics of die casting and injection molding. Many large plants produce new plastics and zinc and aluminum die casting are one area, into which plastics can move. While the basic raw material price of plastics is more and Young's modulus is less than die cast materials, comparisons incorporating specific gravity and processing, show some plastics away ahead in many items. A typical example is the instrument cluster housing of an automobile, which costs $1.08 for .092" thickness of polypropylene, $2.36 for .069" of delrin and $2.95 for .060" of zinc.

Golden Gate

Vinyls Discussed

THEO. V. MALIANNI

On Feb. 18, forty-two members and guests of Golden Gate Section met at International Inn for their regular monthly meeting. The following 1960 officers were introduced: Brant Newsom, president: Bill Hill, vice president; Scotty Allen, secretary; and Bob Wnukowski, treasurer.

After dinner, a short business meeting was presided over by President Brant Newsom. S.P.I. President, Fred Kennerly of Kennerly-Spratling, outlined the March 10 meeting of SPI, which will include a tour of the Palo Alto Lockheed installation. He extended a cordial invitation to all SPE members. After introduction of guests and members, President Newsom turned the meeting over to Gay Maclise who introduced our speaker, Mr. Vincent L. Murphy, Vice President of Ellay Rubber Co. in Los Angeles. Mr. Murphy's subject was "Some aspects of Vynel Calendering and Compounding." At the present time, Ellay Rubber possesses the only plastic calender on the coast and this machine produces 20,000 lbs. per day in thicknesses of .006 to .020 in 48" max. width. A new machine that will double this output is now being built. Mr. Murphy explained that in calendering, PVC is plasticized only to soften, toughen, and increase flexibility. A stabilizer is used to preserve quality and appearance. One of the newest developments is a lead filled vinyl sheeting to protect against radiation. Other fast growing markets are vinyl film for stirring whole blood; medical tubes for use in the human body; vinyl basketballs and volley balls; vinyl luggage to stand a minus 20 degree F; and vinyl covered wires and cables.

Ontario

Polypropylene

HAROLD SHURE

The February meeting of the Ontario Section was as follows:—

Place: Toronto, Ontario.
Date: Thursday, February 18th, 1960.
Attendance: 107 persons.
Subject: "Properties and application of polypropylene plastics".

Speaker: Mr. J. I. G. Bell, Assistant Sales Manager Plastics—Technical Service Section. Canadian Industries Limited, Montreal.

The basic characteristics of polypropylene were discussed. The impact this material was having on end-use markets, (including injection molding, film, textile, wire and cable, bottles and pipe) was also covered.

The Ontario Section welcomed Past International President Mr. F. C. Sutro to Toronto area.. Unfortunately he was on a brief business visit and was therefore unable to attend a meeting to meet all the members.

On February 23rd, the last lecture of the 1959-60 Session at the University of Toronto extension course was given. Of the 235 registered students, over 200 attended 80% of the lectures. In appreciation of the work Prof. W. G. MacIlhinney has done for this SPE sponsored course, Ontario Section President Harry Watson presented him with an inscribed desk set on behalf of the Section. Education Committee Chairman James Parkhill explained that the two year course would continue next October, and new student registration will be welcome.

TECHNICAL MEETINGS CALENDAR

17th ANTEC

Annual Technical Conference—January 24-27, 1961, Shoreham Hotels and Sheraton Park Washington, D.C. Sponsored by the Baltimore-Washington Section. General Chairman: Dr. Gordon Kline, National Bureau of Standards, Washington, D. C.

1960 RETECS

Offers of papers in the technical area of each Regional Technical Conference are solicited by each sponsoring Section. Please submit offers and abstracts to RETEC Chairman or Section President indicated below for each RETEC:

April 20—Plastics in the Petroleum and Chemical Industries, North Texas Section, Hotel Texas, Fort Worth, Texas. Chairman, Raymond S. Perkins, c/o Southwestern Pipe Co., P. O. Box 117, Mineral Wells, Texas.

September 8 and 9—New Horizons in Shoes and Vinyls, Eastern New England Section, Statler-Hilton Hotel, Boston, Mass. Co-Chairman, Program, Robert Abeles, c/o Elfskin Corp., Main St., Cherry Valley, Worcester, Mass.

September 22—Plastics in Business Machines, Binghamton Section, Sheraton Inn, Binghamton, N. Y. Chairman; John E. Gwyn, c/o Consolidated Plastics, 498 Conklin Ave., Binghamton, N. Y.

October 5—Plastics in Corrosion, Golden Gate Section. Chairman: J. W. Richardson, c/o Rohm & Haas Co., 600 California St., San Francisco 8, Calif.

October 19—Tooling for the Plastics Industry, New York Section, Hotel Commodore, New York City. RETEC Chairman—Arnold Meyer, 1877 Palmer Ave., Larchmont, N. Y.

November 7—Automation in Injection and Compression Molding, Ontario Section, Toronto, Ontario. Chairman: J. M. Lees, c/o Canadian General Electric Co., 755 Division St., North Cobourg, Ontario, Canada.

November 18—Blow Molding, Newark Section, Essex House, Newark, N. J. Chairman: Robert Hoehn, Mack Molding Co., Ryerson Ave., Wayne, N. J.

SPI COMING EVENTS

April 7, 8—Seventeenth Annual SPI Western Section Conference, The Society

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SECTION NEWS

Philadelphia

Thermosetting Equipment and Molding

GEORGE R. DeHOFF

February 23 was Thermosetting night for the Philadelphia Section. Over 110 members and their guests were present for the program prepared by Chairman, E. L. Derowski of Oak Engineering Company. Continuing with the panel type meeting that Philadelphia has been using this year to cover a subject comprehensively in one evening, three speakers were on hand. H. L. Maiocco of F. J. Stokes Company discussed "Advances in Thermosetting Equipment," Vince Wagner of W. T. LaRose Company reviewed "Preheating and Preconditioning of Material as an Adjunct to Molding," and E. W. Vaill, Union Carbide Plastics Company, presented the "Latest Developments in Phenolic Molding Techniques."

Mr. Maicco defined the differences between automatic and semiautomatic compression molding and described the capabilities of modern day presses. In the field of automatic transfer molding he pointed out that, although there are still many problems, automatic transfer molding with inserts is a reality.

Mr. Wagner, in discussing preheating, listed ten advantages that modern preheating equipment offers the molder. These ranged from being able to handle bigger jobs on a given press to getting better quality in the finished part.

Mr. Vaill, discussing the latest developments in phenolics, presented data on gate size and area relative to the net weight of the part recommended that, for automatic molding, a performed and preheated feed be used. Preform hardness and temperature should be carefully controlled.

of the Plastics Industry, Inc., New Riviera Hotel, Palm Springs, Calif.

April 20, 21—Cellular Plastics Division Automotive Conference, The Society of Plastics Industry, Inc., Statler Hotel, Detroit, Mich.

April 20, 21, 22—Third Annual Fluorocarbons Division Meeting, The Society of the Plastics Industry, Inc., Hotel Roosevelt, New Orleans, La.

April 25, 26—Eighteenth Annual SPI Canadian Section Conference, The Society of the Plastics Industry (Canada), Inc., London Hotel, London, Ont., Canada.

October 13, 14—Sixteenth Annual SPI New England Section Conference, The Society of the Plastics Industry, Inc., Wentworth-by-the-Sea, Portsmouth, N.H.

SPI EVENTS—1961

February 7, 8, 9—Sixteenth Reinforced Plastics Division Conference The Society of the Plastics Industry, Inc., Edgewater Beach Hotel, Chicago, Ill.

April 20, 21—Eighteenth Annual SPI Western Section Conference, The Society of the Plastics Industry, Inc., Hotel del Coronado, Coronado, Calif.

June 5-9—Ninth National Plastics Exposition, Sponsored by The Society of the Plastics Industry, Inc., Coliseum, New York City.

June 5-9—SPI National Conference Sponsored by The Society of the Plastics Industry, Inc., Commodore Hotel, New York City.

CONGRESS FOR MACROPLASTICS

The International Congress for Macroplastics will be held on **October 17-19, 1960,** Utrecht, Netherlands.

DETROIT RUBBER and PLASTIC GROUP MEETINGS

April 22—Spring Meeting, Detroit Leland Hotel.

June 24—Summer Outing, Western Country Club.

October 7—Fall Meeting, Detroit Leland Hotel.

December 9—Christmas Meeting, Statler-Hilton Hotel.

SPE Members:

Get the most out of your membership in SPE by becoming active in the Professional Activities Group in your field. Here are the 1960 PAG Chairmen to contact:

PLASTICS IN BUILDINGS
Armand Winfield
Debell & Richardson
Hazardville, Conn.

PLASTICS IN ELECTRICAL INSULATION
Walter A. Gammel, Sr.
Automatic Process Development Corp.
1170 Morris Avenue
Union, New Jersey

EXTRUSION
Ernest Bernhardt
E. I. du Pont de Nemours & Co., Inc.
Wilmington, Delaware

REINFORCED PLASTICS
George Lubin
Grumman Aircraft Engineering Corp.
Bethpage, L. I., N. Y.

INJECTION MOLDING
Roger B. Staub
Union Carbide Plastics Co.
River Road
Bound Brook, N. J.

METAL MOLD DESIGN AND CONSTRUCTION
David R. Edgerton
Lindberg Steel Treating Company
1975 North Ruby Street
Melrose Park, Ill.

CASTINGS AND PLASTICS TOOLING
J. D. Bassin
K D K Plastics Co.
Harpursville, N. Y.

FORMING
Donald Wood
Plax Corp.
Hartford, Conn.

FINISHING
Tom Hayden
Bee Chemical Co.
Logo Division
12933 So. Stony Island Avenue
Chicago 33, Ill.

THERMOSETTING MOLDING
Robert W. Bainbridge
Durez Plastics Division
Hooker Chemical Co.
North Tonawanda, N. Y.

VINYL PLASTICS
Saul Gobstein
Ferro Chemical Corp.
Box 607
Emerson, N. J.

POLYMER STRUCTURE AND PROPERTIES
Herman S. Kaufman
Allied Chemical Corp.
152 Golf Court
Teaneck, N. J.

STANDARDS FOR REPORTING PROPERTIES
L. B. Allen
Plastics Laboratory
I B M Corporation
Endicott, New York

PLASTICS IN THE AUTOMOTIVE INDUSTRY
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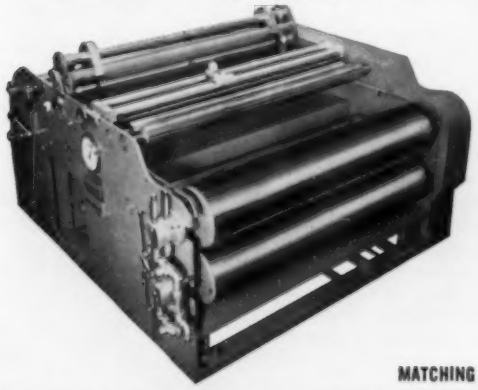

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NEW BOOKS

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Maurice Morton, Reinhold Publishing Corp., 539 pages, $10.00

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In addition to being well documented and complete in its coverage, this book also offers entertaining reading. A rare combination for a technical text.

A history to rubber and an introduction to polymer chemistry begin the book. From there the author leads into natural rubber and the many facets associated with rubber such as vulcanization phenomenon, additives and compounding. Rather extensive data is given and natural rubber is treated fully in the text.

Following 7 chapters devoted to natural rubber, the book delves into butadiene-styrene, nitrile, acrylate, butyl, neoprene, polysulfide and silicone rubbers. Each of these topics is also excellently covered and outlined.

The final chapters deal with reclaimed material, latexes, sponges, physical testing and process equipment.

Introduction to Rubber Technology is an excellent text be it for a university curriculum, an engineers library or for general reading on a fascinating subject. This book should be on everyones bookshelf.

Alexander Jung
Rohm and Haas Co.

THE NATURE AND PROPERTIES OF ENGINEERING MATERIALS

Zbigniew D. Jastrzebski, Professor of Chemical Engineering, Lafayette College, John Wiley and Sons, Inc., New York, 550 pages, $11.00

Ordinary matter consists of atoms which are the structural units of all solids, liquids and gases. An understanding of the nature and properties of engineering materials must ultimately be based on an understanding of the manner by which atoms combine and act together. This text stresses the fundamentals.

The author begins with the structure and dimensions of atoms, the forces existing within and acting between them and their aggregation into matter. He deals with the properties of crystals, colloids and gels, as well as the formation, morphology and properties of high polymers, including the stereospecifics.

The basic concepts of phase transformations are described, including nucleation, polymorphism, phase transitions, solid solutions, intermetallics and eutectics. The more basic aspects of elasticity, plasticity, flow and failure mechanisms are discussed, as are the effects of ionizing radiations and the electrical, magnetic and electronic properties of matter, making frequent reference to the solid-state and other concepts of modern physics.

There is an unusual exposition of the ideas underlying the thermal properties of matter, including free-electron heat transport, phonon conduction and radiations as mechanisms for heat-transfer in metals and dielectrics. Excellent chapters on wear, lubrication, corrosion, and the principles of heat-treatment are included.

Lest it be thought that this is really a physics text, it should be pointed out that the theory is tied in closely with the properties of practical materials and that extensive sections are interspersed which describe the origins, properties and processing of the industrially important metals, ceramics and glasses, polymers and plastics, cements, concrete, lubricants and protective coatings.

Too little space is devoted to adhesion, organic adhesives and structural bonding. By comparison, too much is devoted to inorganic cements, which, however, are treated in a masterly fashion.

The author has introduced an intriguing and highly educational set of problems in each chapter with ample references and selections for further reading. The text is arranged so that the subject matter, after the first four chapters, may be adjusted to whatever the course requires or time permits. Many advanced topics are blended into the general treatment.

Professor Jastrzebski has made a major contribution to the literature of engineering materials. This text is recommended for use in undergraduate and in-plant engineering courses and as a useful addition to the reference shelf.

H. A. Perry
Staff Consultant on Materials
U. S. Naval Ordnance Laboratory

Next Month in The SPE Journal

• Maintenance of Extrusion Equipment

including preventive maintenance, installation, cold starts, and lubrication information.

• Molding Polypropylene

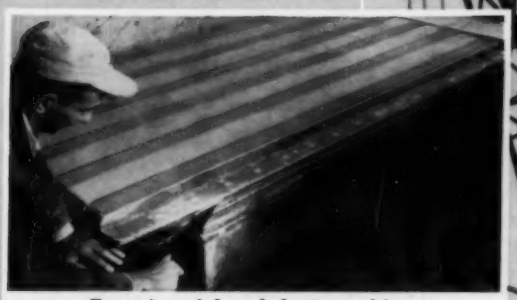
Flow is improved by increasing cylinder temperature, injection pressure, melt index, mold temperature, and gate size.

• Heat Shrinkable Polyester Film Laminate

New polyester film shrinks 30% uniformly in all directions. Packaging applications loom on the horizon.

• Urethanes in the Shoe Industry

An SPE Journal report on a specialized application of castable urethane liquids and coatings for use in the shoe industry.



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Installing epoxy-glass panel in steel frame during assembly of structure.

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Employment & Service Guide

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EUROPEAN CHARTER FLIGHTS FOR MEMBERS

1. June 17 to Brussels, returning July 4. Deadline for application May 10.

1a. In case of sufficient support only: June 10 with connection to Moscow (International Symposium for Macromolecules) Deadline May 10.

2. July 29 to Paris and Vienna (Salsburg Festivals) returning Aug. 12. Deadline June 10.

2a. In case of sufficient support: connection to Tel Aviv. Deadline June 10.

3. October 6 to London, returning from Amsterdam or Brussels Oct. 23. (International Synthetic Rubber Symposium and Exhibition in London Oct. 11, 12, 13, International Congress for Macroplastics in Amsterdam Oct. 17-19, and Macroplastics Fair in Utrecht, Holland Oct. 19-26. Jet Flight both ways.) Deadline July 25.

The round trip fare (first class service) $270 to $300.00 per person. Applicants should mail their deposit check for $20.—per person payable to Dr. Heinz Neunteufel—European Flight Account to the European American Plastics Institute, 116-16 Audley St., Kew Gardens 18, N.Y.

The EUROPEAN AMERICAN PLASTICS INSTITUTE can give assistance to participants of the flights:

- In hiring European engineers or plastics experts
- in providing offers for machinery, tools and raw materials
- in establishing business connections for European representation
- in acquiring or selling patents or licenses
- in obtaining analysis of European markets
- in setting up a European branch, production plant or sales office.

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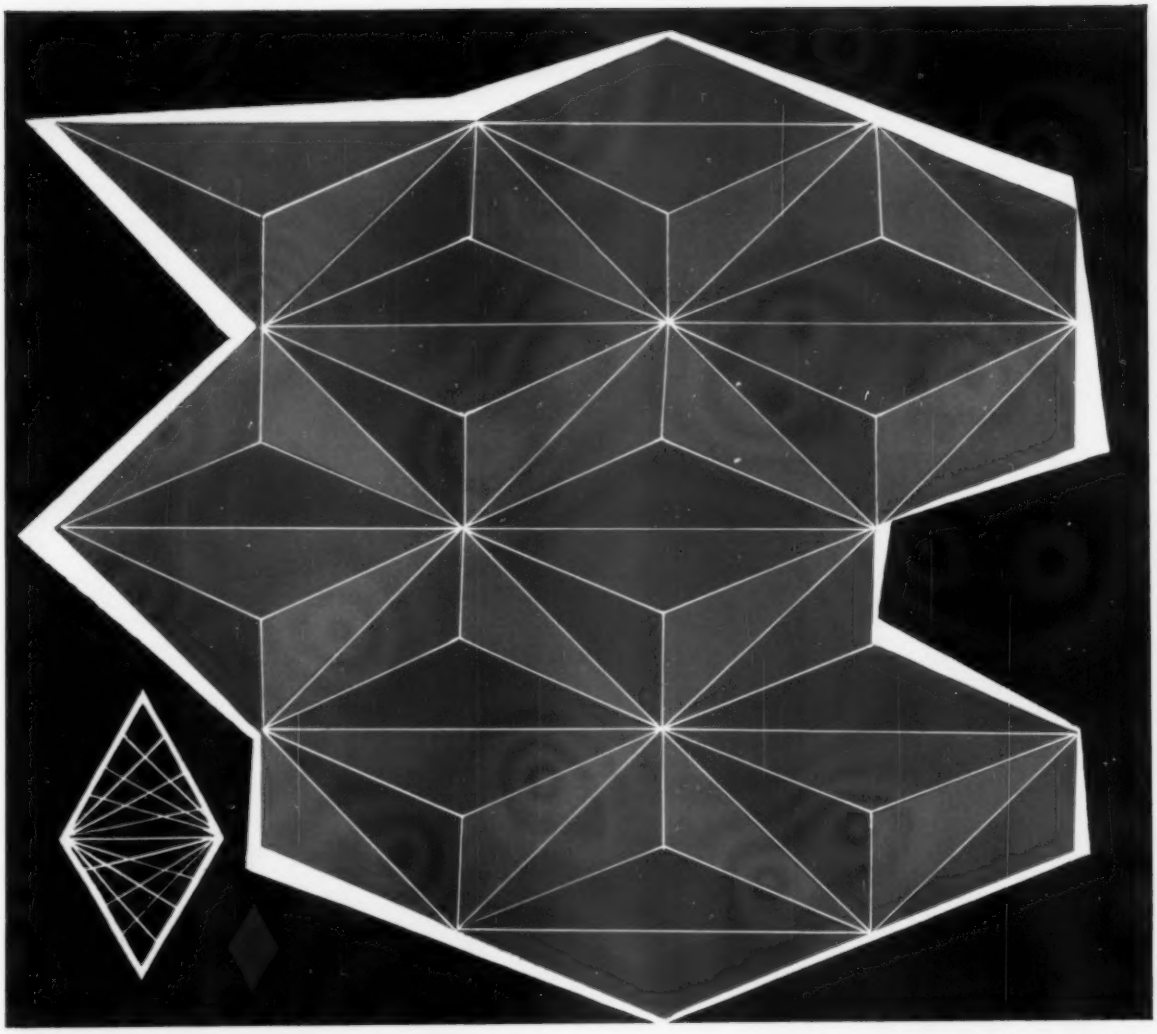

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